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16. Abstract

The book is devoted to a discussion of the spaceflights by Soviet devices to the Moon and the results of the research which they carried out on the lunar surface. The work performed by the "Lunokhod-1" is described and the results of an analysis of the samples of lunar rock brought back to Earth by the "Luna-16" are presented. Data are included on the flight of the "Luna-20" station which brought material from the lunar mountains back to Earth.

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V. Alekseyev and L. Lebedev
Editor G. S. Narimanov[1]

THE RIDDLE OF THE MOON /3*

Man has always striven to understand that which is new and unknown in the world around him. Since time immemorial his sights have been directed at the skies, where he saw the Sun, the Moon, the planets and myraids of stars. Man wanted to understand the basic laws which controlled the world around him and its evolution.

The ancient Greeks already knew a great deal about the Moon. Democritus declared that the markings on the Moon were enormous mountains and valleys. Aristotle demonstrated the spherical shape of the Moon. The Greeks understood that the Moon revolves around the Earth and simultaneously rotates on its axis, with the period of orbital revolution being equal to the period of rotation of the Moon on its axis. Approximately 1,900 years before Copernicus the Greek scientist Aristarchus proposed a heliocentric model of the Solar System. He calculated the distance to the Moon and estimated that it was 56 times greater than the radius of the Earth. Hipparchus found that the orbit of the Moon is oval in shape and located in a plane which is inclined at 5° to the plane of the orbit of the Earth, i.e., to the plane of the ecliptic. He showed that the plane of the Moon's orbit rotates relative to the celestial sphere and completes one rotation in 18 and 2/3 years. Hipparchus succeeded in estimating the diameter of the Moon to within 31 minutes of angle and determined the relative distance to the Moon, figuring it to be 59 Earth radii. In the second century A.D. Ptolemy ascertained the parameters of the lunar orbit.

Hence, about 2,000 years ago the ancient philospher-scientists who observed the Moon only with the unaided eye knew about the spherical shape of the Moon and suggested that its weather was similar to that on Earth, and that its surface consisted of large valleys and mountains; they were familiar with the nature of its revolution around the Earth along an oval orbit and the approximate dimensions of that orbit.

They were aware of the equalities of the angular velocities of the revolution of the Moon around the Earth and the rotation of the Moon on its own axis, which governs the constant orientation of the Moon with respect to the Earth. They correctly explained the sequence of the changes in the phases of the Moon, caused by the change in the relative position of three bodies — the Moon, the Earth and the Sun.

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[1]Doctor of Physical-Mathematical Sciences.
*Numbers in the margin indicate pagination in the foreign text.

During the Middle Ages, when the Church and the Inquisition ruled, many of the works of the ancient astronomers were destroyed. The Renaissance again awakened scientific thought. The astronomer Tycho Brahe (1546-1601) added a great deal to knowledge about the movement of the Moon and collected a large body of data which was of considerable significance in further research. /4

The science of the Moon profited greatly on the basis of the work of Kepler (1571-1630) who formulated the laws of the motion of the planets, Newton (1642-1727) who established the basis of modern mechanics and formulated the law of universal gravitation, Galileo (1564-1642) who used the telescope to study the heavenly bodies.

The great ideas and discoveries of science during the Renaissance made possible an intensive study of the Universe, and effected changes in the view of the world and the methods of investigation of scientific and technical problems. The basis for many of the modern concepts regarding the Universe can be found in the achievements of that era. Knowledge concerning the characteristics of the motion of the Moon, its mass and size was considerably augmented.

Observations of the Moon by means of optical instruments made it possible to obtain considerable important information about the principal formations on its surface. Thus, Galileo, using a very simple spyglass, the remote ancestor of modern telescopes, discovered the mountains on the Moon and estimated their height on the basis of the length of the shadows they cast. Together with Hevelius, he compiled a very accurate and detailed map of the visible hemisphere of the Moon.

Beginning in those days, knowledge about the Moon has continued to grow without interruption. Many years of observation of the lunar surface from the Earth have provided considerable information about the Moon.

The use of modern devices based on the latest achievements of science and technology for observing the Moon has made it possible to get a precise idea of the dimensions of the Moon and the parameters of its orbits, the shape and location of the details of the relief, to get some idea of the temperature conditions on the lunar surface, the color of the lunar soil, the laws of scattering of light, radiation, etc.

We now know, for example, that the distance from the Earth to the Moon varies from 406,697 to 356,410 km, while the average distance is 384,400 km or 60.2673 equatorial radii of the Earth. The inclination of the Moon's orbit to the plane of the ecliptic amounts to $5^\circ\ 8'$ and $43''$, and changes with respect to the Earth's equator within the limits of 23°, $27' \pm 5^\circ\ 9'$. The period of the Moon's rotation around the Earth is 27.3217 days, which coincides with the period of rotation of the Moon on its axis. The angular diameter of the Moon, as seen at the average distance from the Earth, is equal to $31'\ 5.6''$ and the diameter is 3,476 km. The ratio of the mass of the Moon to the mass of the Earth is 1:81.3030, and the acceleration due to the force of gravity on the surface of the Moon is 0.166 of

the acceleration on Earth. It has been found that the average density of the Moon with respect to the density of water is only 3.34, while on Earth it is 5.52. This indicates the absence of any important heavy masses (metals) in the /5
core of our satellite. The Moon is evidently composed entirely of rock, which is in agreement with current information about the lack of a magnetic field on the Moon.

Until recently, it was impossible to distinguish on the surface of the Moon details measuring less than 300 m as viewed from Earth, so that many data concerning the details of the relief were lacking.

Likewise, information on various physical characteristics of our satellite and its surface were very limited. Such characteristics of the Moon as the chemical and mineralogical composition of the surface, the structure of the lunar core, and the seismicity of the Moon were hypothetical in nature. Physical conditions on the Moon are quite different in terms of terrestrial concepts — a high vacuum, considerable temperature variations from $+130^\circ$ during the lunar day to -160° Celsius during the lunar night, the action of corpuscular x-ray and ultraviolet radiation from the Sun for billions of years, the continuous fall of meteorites, the low force of gravity, etc., were felt by scientists to be responsible for the special structural characteristics of the lunar surface that are unknown on Earth, therefore on the basis of information that was obtained as the result of terrestrial observations, various theories were propounded concerning the dust cover of the Moon, the pumice or slag-like structure of its surface, special lattice-like mineral structures that do not exist on Earth, and were formed by accumulation of small particles of lunar soil, and lava flows of basalt type.

A characteristic feature of the lunar relief is the numerous craters. It has been suggested that they were formed as the result of the fall of meteorites onto the lunar surface. The large craters can reach 250 km in diameter. Their depth is small in comparison with their diameter. The bottoms of the craters are located below the surrounding terrain. The craters have walls whose height above the surface is less than the depth of the crater. It has been calculated that the volume of material forming the walls is practically equal to the volume of the part of the crater which is below the surface. This apparently supports the "meteorite hypothesis."

However, the fall of large meteorites is a very rare phenomenon. Therefore, many scientists have felt that the formation of the lunar relief occurred as the result of volcanic activity. In 1958 the Soviet N. Kozyrev suggested a very important fact in favor of this hypothesis; he had observed the release of a large amount of gas from the central portion of the crater Alphonsus. Then other occurrences of the internal activity of the Moon were recorded. The struggle between those who favor the volcanic origin of the craters and those who favor the meteoritic view has not yet been concluded. It is possible that the large lunar craters are of volcanic origin and the fall of meteorites contributed to the formation of many of the small craters.

There are theories which deal in various ways with the origin and the history of the Moon. The oldest of them states that the Earth and the Moon /6 constitute a double planet and that they both arose as separate bodies, linked with one another in space, from a single cosmic cloud composed of dust or gas. However, the mechanism for the formation of such a double planet has not been worked out, and this theory is only held by a few scientists at the present time.

At the beginning of our era, the theory of the English scientist J. Darwin was very popular. In these days it was considered that the Earth began its existence in the form of a hot liquid mass and the Moon was formed as the result of the separation of the part of the mass of the Earth. At the present time, there are serious reasons for considering that both the Earth and probably the Moon were formed as cold bodies and therefore separately.

In recent years, still another theory has come to light which was worked out by the Swedish physicist C. Alfen, which states that the Moon was originally an independent planet which came into the sphere of attraction of the Earth and was trapped by it.

The study of the Moon and planets of the Solar System is an extremely important tool for the formulation of a general theory of the origin of the Earth and its natural resources, for obtaining information about the earliest stages of the existence of the Earth, those stages when the principal structural elements of the Earth's crusts were formed. Automatic spacecraft have brought back important data about the heavenly bodies, whose comparative study will make it possible to work out general laws of structure and history of planets, and to compare the course of geological processes on different bodies in the Solar System.

Our natural satellite, in its own way a reservation in the Universe has retained its relief in almost the original state. Due to the lack of water and atmosphere on the Moon, the changes in its surface occur very slowly, much more so than on Earth. As a result of the action of various types of erosion, all of the noticeable traces of the original structure of the Earth have been destroyed. Now we know very little about the early stages of its evolution. By studying the lunar relief we will be able to learn the nature of a number of geological processes that occurred on the Earth in the past.

Scientists still do not know enough about the chemical evolution of the Earth's crust. The Moon can serve as an example of incomplete evolution and possibly may be the best object for allowing us to learn how the Earth's crust looked before.

The use of spacecraft to study the Moon and planets of the Solar System will provide the answers to many problems which have remained more or less puzzling to astronomers throughout history.

On the Road to Discovering the Secrets of the Moon /7

The launching of the first artificial Earth satellite on the 4th of October 1957 by the Soviet Union opened up a new era in the history of mankind — the era of the conquest of space. Several years went by and in

January 1959 the first spacecraft designed for studying the closest heavenly body to the Earth was launched — the "Luna-1" automatic station.

During the next 12 years, considerable research was carried out involving the Moon and the area of space near the Moon. Automatic stations in the "Luna" and "Zond" series carried out an extensive orderly program of study of our natural satellite.

The first launching of a spacecraft to the Moon made it possible to overcome the limits of the second cosmic velocity and to go beyond the limits of space surrounding the Earth. After flying to the immediate vicinity of the Moon, at a distance of from 5 to 6,000 km from its surface, the "Luna-1" automatic station then became the first artificial planet in the Solar System. Experiments performed by the "Luna-1" station established the lack of a significant magnetic field near the Moon and recorded fluxes of ionized plasma ("solar wind") in interplanetary space. These results made it possible to refine our ideas of the properties of interplanetary space.

In September 1959, the "Luna-2" reached the lunar surface in the eastern part of Mare Imbrium, in the vicinity of the craters Archimedes and Autolycus. The instruments aboard the station carried out measurements in the immediate vicinity of the surface and transmitted to Earth a considerable amount of information containing the first experimental data on the physical properties of the Moon. They were indicative of a lack of any kind of significant magnetic field or radiation belt on the Moon.

On October 4, 1959, on the second anniversary of the launching of the first artificial Earth satellite, the "Luna-3" station was launched, which circumnavigated the Moon and photographed the side which is invisible from Earth. The first Soviet photographs of the backside of the Moon made it possible to see what had been hidden from the eye of man and to give astronomers information about the most important characteristics of the structure of the hemisphere which is invisible from Earth. Photographic study of the backside of the Moon was practically completed by the "Zond-3" station in July 1965. A general survey of the entire lunar surface made it possible to determine the principal characteristics of the distribution of the Mare and continental regions and a complete chart of the Moon and the lunar globe were compiled. There was found that the invisible side of our satellite is completely different in terms of the landscape from that which astronomers have seen and studied. There are only a few Maria on it, and the entire region is occupied by annular formations. These differences in the structure of the two hemispheres of the Moon have not yet been completely explained and constitute the next problem awaiting solution for scientists.

Further study of the properties of the natural satellite of the Earth and the medium surrounding it have required more prolonged stays of scientific instruments in the vicinity of the Moon. A qualitatively new step in the study of its nature began in February 1966 when the "Luna-19" station made a soft landing on the eastern part of Oceanus Procellarum. The time of active existence of the lunar robot on the surface was measured in several days. The panoramas /8 of the lunar surface that were transmitted to Earth made it possible for the first time to see the very fine details of the surface and to estimate the nature of the relief at the site where the station landed. It is clear from the photo that "Luna-9" did not sink noticeably into the soil. It was not buried when it fell, it remained lying for a long time on the surface, and the rocks which could be seen in many points of the panorama were not covered with dust. All of this indicated a rather considerable degree of hardness for the rocks that make up the surface layer of the Moon, as well as a lack of deep layer of dust. At the landing site of the station the surface is covered with craters of various sizes, some diminutive rings to rather large formations, as well as rocks. They were probably ejected from the subjacent layers during the impact of meteorites. The hypothesis of a thick layer of dust had been overturned. By studying the panoramic pictures, the scientists concluded that the surface of the Moon in the area where the "Luna-9" landed most probably was composed of flows of basaltic lava. Dosimetric measurements that were made provided the first information about the existence of radioactive processes in lunar rocks and made it possible to determine the coefficient of reflection of the lunar surface with respect to cosmic rays.

One of the most important problems involved in the study of the Moon is the determination of the chemical composition of the lunar rocks. Considerable interest attaches to the comparative study of the nature of the rocks or the upper layers of the Moon on the scale of the entire lunar sphere. This is a specific problem within the entire complex of lunar research and has required prolonged stays of scientific instruments in the vicinity of the Moon and the collection of measurements from extensive areas. Similar requirements have been imposed on a number of other scientific problems concerning the Moon.

The solution of this group of problems has been possible only on the basis of the construction of artificial lunar satellites. By means of these devices, extremely valuable information has been gained concerning the nature of the Moon. The scientific devices aboard the first satellite, the "Luna-10" station which was launched into sclenocentric orbit on the 3rd of April 1966, made it possible to determine the nature of the lunar rocks on the basis of their content of naturally radioactive elements. Rocks were found on the Moon which are similar in composition to basalts which are widely distributed on Earth.

A study of the variations in the orbit of the "Luna-10" station form the basis of a determination of the characteristics of a gravitational field of the Moon. An analysis of the results of the measurements of the orbital parameters of the "Luna-10" station performed by means of radio indicated that the equipotential surface of the Moon was pear-shaped (a surface where the acceleration of the force of gravity is normal to it at all points) with the convexity located on the backside, i.e., in the direction away from the Earth. /9

As we know, the shape of the surface with a constant force of gravity of a celestial body is determined not only by its geometrical shape but also by the internal distribution of masses. The results that were obtained are of a practical significance for a determination of the structure of the gravitational field of the Moon and constitute the first step along the path to the study of the structure of the core of the natural satellite of the Earth.

As the result of magnetometric measurements carried out by the "Luna-10" it was found that the field in the space around the Moon which has been studied has a rather uniform structure. During the period of the measurements, a variation was observed in the intensity of the magnetic field between 24 and 38 λ , while on Earth it varied from 30,000 to 74,000 λ.

Evidently there are no magnetic fields on the Moon and the lunar magnetic field by nature is an interplanetary field which is deformed by the Moon.

Studies of the Moon and the space near the Moon were continued by the "Luna-11" station, the second artificial satellite of the Moon which was launched into orbit on the 27th of August 1966. The scientific program was supplemented by the study of the longwave cosmic radiation. The data which was obtained made it possible to confirm and expand the basic conclusions which were drawn on the basis of the results of the research which was conducted by the "Luna-10" station.

The third Soviet artificial satellite of the Moon the "Luna-12" station, launched into orbit around the Moon on the 25th of October 1966, in addition to carrying out the research begun by the first 2 lunar satellites, was faced with a new problem: the photography of certain areas of Mare Imbrium from altitudes of 100 to 340 km. This was necessary both for a detailed study of the lunar surface and the nature of the formations on it and for a compilation of more accurate charts.

The photographs of the region of bright rays extending outward from the crater Arastarchus were particularly interesting. They showed an increased concentration of small craters in those areas which are characterized by increased brightness on the basis of terrestrial observations. In the pictures, one could make out details of the relief that were 15 to 20 m in diameter. The craters were evidently formed by the ejection of fragments of rock from a focus of volcanic activity or by the fall of a meteorite onto the lunar surface. It is possible that the source of such emissions in this area was the crater Arastarchus.

An important contribution to the study of the Moon was made by the "Luna-13" automatic station which made a soft landing in the vicinity of Oceanus Procellarum in December 1966.

In addition to the panoramas of the lunar surface that were transmitted to Earth, "Luna-13" carried out a cycle of scientific experiments. For the first time, direct measurements were made of lunar soil and its mechanical properties by means of a soil sampler and penotrometer and a radiation densitometer. These devices were deployed by a special mechanism to a distance of 150 cm from the housing of the station in an area which was not disturbed by the landing. The interpretations of the readings of the instruments indicated that at the point where the "Luna-13" station landed there was a layer of material /10 on the surface which had a specific gravity $\lambda \approx 0.8$ g/cm^2, composed of grains and granules of a porous mineral substance, adhering weakly to each other. The data that were transmitted from the "Luna-13" station confirmed the fact of considerable hardness of the soil which had been established at the time of the experiment with the "Luna-9." The results of the measurements considerably expanded knowledge concerning the properties of lunar soil. This information enabled Soviet scientists and designers to proceed with assurance in designing automatic stations of a new type. They had to solve the problem of building new improved means for further study of the Moon.

The problems that would be solved by means of artificial lunar satellites included not only questions relating directly to the Moon but also problems involving the Earth-Moon system. The program of scientific research for the 4th Soviet artificial satellite of the Moon, the "Luna-14" station which was launched in April, 1968, was aimed at a solution of several aspects of this problem. In particular, the information on the ratio between the masses of the Earth and the Moon was refined. This ratio is of great importance for astronomy and its determination has been the subject of many years of observation from observatories on Earth. The program of experiments included systematic observations of the orbital parameters of the satellite for the purpose of determining the characteristics of the gravitational field of the Moon, studying the conditions for transmission of radio signals between the Earth and the automatic station when the latter was in various positions relative to the lunar surface, and also during the passages of the station behind the Moon. The study of the fluxes of charged particles coming from the Sun, cosmic rays and other research that had been begun by the first lunar satellites was continued.

The problem of returning the scientific laboratories from space to the Earth was solved in the course of the flights of the "Zond-5" (September 1968) and "Zond-6" automatic stations (November 1968). These devices, which circumnavigated the Moon and successfully carried out a program of planned scientific experiments, entered the Earth's atmosphere at the second cosmic velocity, both after ballistic launching ("Zond-5" station) and descent using aerodynamic characteristics ("Zond-6" station) and made a landing in the specified areas of the globe. During the flight of the "Zond-5" station scientific measurements were conducted as well as photography of the Earth from a distance of about 90,000 km. The "Zond-6" station, in addition to carrying out scientific studies in space near the Moon, conducted two photographic sessions involving the Moon from a distance of about 11,000 km and from a distance of about 25,000 km.

In August 1969 and in October 1970, the "Zond-7" and "Zond-8" automatic /11
stations made their flights. In the course of these experiments, physical investigations were carried out along the flight path and in space around the Moon, and color photographs of the Earth and Moon at various distances from the object of photography were made.

What were the scientific problems that were solved by means of "Zond" series of stations? In the first place, these were observations of the Moon from close up and from directions which are not accessible for observers on

Earth. Until recently, the shape of the Moon, as we have already mentioned, was studied only on the basis of information from ground observations of the side that could be seen from Earth. Artificial lunar satellites make it possible to study the Moon's gravitational field, which is related to the dynamic figure of the Moon. In order to relate the gravitational field to landmarks on the lunar surface, study its physical nature, geological structures, it is necessary to know the shape of the physical surface itself. Photographs of the Moon taken by means of the "Zond" station from a short distance away and from different directions have made it possible to obtain an idea both of the visible and invisible parts of the lunar surface. Precise stereoscopic measurements make it possible to construct a spatial model of the Moon and to determine its shape.

Another scientific goal of the "Zonds" is the detailed study of the lunar surface and the nature of the formations on it at points which are inaccessible or inconvenient for observation from Earth. In particular, interest is attached to understanding the characteristics and topography of the backside of the Moon. Equally important is the study of the physical and optical properties of the lunar rock and the geological structures by means of precise photometric examination of the photograph.

Among the applied scientific problems of the experiments are the perfection of a system of coordinates on the lunar surface in the boundary zones of the disc which is visible from Earth and their extension from the backside of the Moon, as well as the compilation of more accurate charts which are necessary for scientific investigation, orientation of flights in space around the Moon with time and the linking of the orbits of spacecraft to the physical surface of the Moon.

Important information concerning the Moon has been obtained by means of American automatic devices as well. The expeditions to the Moon of the American astronauts aboard the "Apollo" spacecraft have required the solution of many complex problems associated with the landing of man on the lunar surface. This constituted a new step in the study of the Moon.

The successful flights of the automatic stations in the "Luna", "Zond" series as well as the "Venera" stations have shown with great certainty that at the current stage of development many scientific problems involved in the study of the Moon and planets can be successfully solved by means of automatic devices which have proven their effectiveness many times.

Soviet scientists and designers are faced with the problem of further improvements in space robots, using them to solve new theoretical problems. The advanced status of Soviet science, the high level of socialist industrialization /12
have made it possible to build automatic devices of the new type which are opening up wide horizons for carrying out systematic scientific investigations of heavenly bodies by means of automatic devices.

For Lunar Rock

Thirteen years have gone by since the day when the whole world heard the word "Sputnik" and adopted it into spoken languages; it opened up a new era for the world, the era of spaceflight.

Now it is the 12th of September, 1970. The Kazkakh steppe in autumn. We are at the Cosmodrome. It is evening. A rocket of a new generation is straining on the launch pad, more powerful than the rockets that launched the "Luna-9" and "Luna-13" stations.

The service gantry moves away. No people to be seen. At the command point, in an underground bunker, there is a tense silence interrupted only by the words of sharp commands. The controllers are ready behind their panels. The bulbs of monitoring devices twinkle, indicating that the onboard systems of the rocket and the launch complex are ready.

In accordance with the set program, automatic devices are performing one operation after another to prepare the rocket for the launch, simultaneously checking for the last time the function of all the systems of the rocket.

At 1626 Moscow time the glowing display panel counts off the last seconds prior to liftoff: 3 - 2 - 1 - 0.

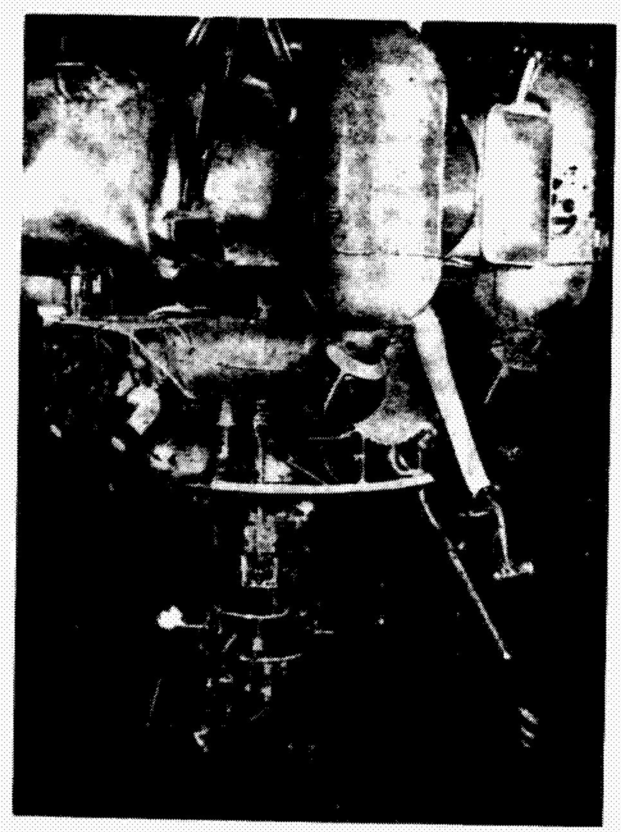
A brief word rings out like a shot: "liftoff!"

A blinding light sears the area. The Earth trembles. A thunderous roar spreads out across the steppe. In a few seconds the rocket has disappeared in a cloud of smoke. Then, slowly at first, then faster and faster, as if it were rising on a trail of fire, the rocket strains upward, carrying with it the automatic "Luna-16" station, shielded beneath the nose cone.

Several tenths of a second have gone by, and only the roar, hushed by the distance, but still clear, moving across the starry sky of evening tells of the event which has occurred.

From the loudspeakers, through a soft hissing sound, come the words of reports from ground measuring points and ships on the flight of the rocket. Finally the first stage of the flight of the carrier rocket is complete, as indicated by the clear words of the report. "The 'Luna-16' station together with the last stage of the carrier rocket has entered orbit as an artificial satellite of the Earth with orbital parameters that are close to those that were calculated! The maximum distance of the station from the surface of the Earth is 212.2 km and its incliniation to the plane of the equator is 51° 36 '.

After 70 minutes of flight, when the station was over the southern vastnesses of the Atlantic Ocean, on command from onboard programmer-timer devices, a switch was closed at the appointed time and the engine of the last stage of the rocket separated, giving the station a carefully calculated additional velocity, monitored by a control system which was necessary to put the station into a trajectory for flights to the Moon. /13



The "Luna-16" Automatic Station

The brief laconic words of the Tass report were as follows:

"In accordance with the program of space research, on the 12th of September 1970, at 1626 Moscow time, the automatic station "Luna-16" was launched in the Soviet Union.

The goal of the flight of this station is to perform scientific research on the Moon and in space around the Moon..."

The automatic station "Luna-16" was on its way on a long and difficult path — for lunar rocks.

Soviet engineers and designers, who have brought to life, step-by-step, the space research program, undertook to solve a theoretically new problem in cosmonautics — to bring back to Earth a sample of lunar soil by means of an automatic spacecraft.

It was necessary to solve a number of complex engineering and technical problems to do this.

The first was to launch the station and make it travel through space between the Earth and the Moon, then to inject the station into circular orbit as an artificial satellite of the Moon with specific orbital parameters.

The second was to achieve an automatic soft landing of the station from the orbit of an artificial satellite, in a specified region of the lunar surface.

The third was to collect samples of lunar rock by means of an automatic device and pack them hermetically in a container.

The fourth was to enable an automatic rocket to take off from the lunar surface, travel from the Moon to the Earth, and land in a specified region in the territory of the Soviet Union. /14

The fifth was to solve the problem of returning to Earth an ejection device carrying samples of lunar soil, and to find it after its descent by parachute.

While the first of these tasks had already been solved successfully by Soviet cosmonautics, the latter still awaited solution.

It is important to remember in this regard that it is not very important to solve each of these problems individually; they must be combined into a single whole, assemble them, ensure their mutual correlation, and ensure that various systems, apparatus and mechanisms will work side-by-side with a high degree of accuracy and reliability.

The development of the "Luna-16" station began on the drawing board, in the design offices, at various experimental installations, in fire and cold, in the pressure chamber and on the vibrating stand, in the wind tunnel and in both dynamic and static tests, in the rays of the Sun and in the antenna farm, during aircraft and helicopter tests, in the test area, on the centrifuge and in the water. Finally, electrical and electronic ground tests of the fully assembled station in accordance with the complete flight program.

All of the systems of the station, all of the apparatus, every mechanism and assembly, every detail was subjected to similar testing.

The labor of many tens of thousands of individuals went into this amazing automatic spacecraft, which accomplished a completely new task – the task of bringing back to Earth by automatic means a sample of lunar soil, without the direct participation of man.

"The task performed by the 'Luna-16' is a genuine revolution in the tasks of the conquest of space. You have shown that it is possible by means of the latest automatic systems, without endangering human life, to carry out the boldest of experiments. And I am not surprised, having heard several years ago that a guided Soviet spacecraft had now landed on one of the planets and was carrying out experiments there. I am convinced that the 'Luna-16' will make it possible within this decade, again with the aid of automatic devices, to collect a sample of rock, in particular, from Mars. Indeed, a new country is opening up before us in the field of interplanetary study and research."

This is the way the experiment carried out by the "Luna-16" station was described by the director of the Jodrell Bank Radiophysical Observatory in England, Professor Bernard Lovell.

"Luna-16" /15

The "Luna-16" automatic space station stands before us. It consists of a landing stage with a soil-collecting device and a "Moon-Earth" space rocket with the apparatus to be returned.

The landing stage and the "Moon-Earth" rocket are two independent rocket units which solve diametrically opposite problems. The first ensures a soft landing of the station on the surface of the Moon and the collection of a sample of lunar soil; the second makes possible the liftoff from the Moon and the return of this soil to Earth.

Landing Stage

This design is composed of the following elements:

An engine unit which consists of the basic liquid-fueled jet engine with variable thrust for multiple operation, a system of tanks with fuel components, tubing and two low-thrust engines;

- instrument compartments;

- four shock-absorbing landing struts.

The hermetically sealed instrument compartments of the landing stage contain the following:

Computer and gyroscopic devices for the control and stabilization systems of the station:

- electronic devices in the orientation system;

- onboard receiving-transmitting radio telemetric apparatus, operating on several wavelengths;

- a programming-timing apparatus which automatically controls the function of all the systems, instruments and assemblies in the station;

- chemical storage batteries with regulators and current converters;

- autonomous radio altimeter, which measures not only the height above the surface of the Moon, but also the horizontal and vertical components of the rate of descent of the station during landing;

- the elements of the temperature regulation system;

- telephotometers for transmitting valuable information concerning the spot selected for soil sampling;

- scientific apparatus which makes it possible to determine the temperature and radiational conditions both during the flight of the station and following its landing on the surface of the Moon.

A soil-collecting apparatus, optical sensors of the orientation system, operating elements of this system — gas jet micromotors with a supply of working material (gas) in spherical tanks are all mounted on the outer surfaces of the landing stage.

The soil-collecting device of the "Luna-16" station, which permits drilling and transport of a sample of lunar soil from the surface of the Moon inside a container of the return stage, is composed of 3 basic parts:

a drill with a system of electrical wires and drill bit;

- rods to which the drill is fastened;

- a drive which allows movement of the rod in both the vertical and horizontal planes. /16

In the upper part of the structure of the landing stage, the space rocket for return from the Moon to the Earth is fastened by means of separation charges.

The landing stage also acts as a launching platform.

The "Moon-Earth" Rocket

The rocket consists of the following:

- the engine assembly, consisting of the liquid fueled jet engine and the group of spherical tanks containing fuel;

- cylindrical instrument compartment, fastened to the central tank;

- return apparatus which is fastened to the upper part of the instrument compartment by means of 4 tightening metal strips.

Inside the instrument compartment are the following:

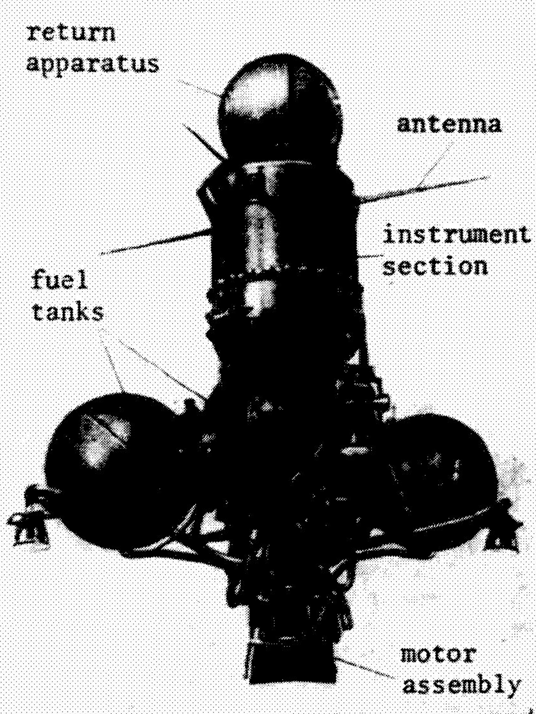
- rocket control system, composed of electronic, computer and gyroscopic devices;

- onboard radio equipment, including a receiver-transmitter section, programming-timer and decoding devices;

- chemical sources of power — batteries with converters and electrical devices for onboard automatic systems.

Four whip receiving-transmitting antennas for the onboard radio system were mounted on the outer portion of the instrument section of the "Moon-Earth" rocket and allowed reception and transmission of radio signals.

The return apparatus was composed designwise of a metal sphere, on whose external surface a special heat-insulating coating had been applied, protecting the internal parts of the apparatus against the action of high temperatures during reentry into the Earth's atmosphere.



"Moon-Earth" Rocket.

The internal space of the return apparatus was divided into 3 insulated compartments: the instrument section, the parachute section and the compartment for the lunar soil. /17

The instrument compartment contained the following: radio-ranging transmitters, intended for detecting the return apparatus following its descent by parachute and following the landing, and onboard program device and automatic elements which control the activation of the parachute system, as well as a chemical storage battery.

The parachute section contains a two-stage parachute system, four flexible antennas of the direction-finding transmitters and two flexible tanks filled with gas from a special tank following opening of the parachute.

The lunar soil compartment was a cylindrical metal container with an intake opening on one side, hermetically sealed by a special lid following placement of the lunar soil in the container.

On the Way to the Moon

The first few days of the flight of the "Luna-16" station passed. The controllers at the Remote Space Communications Center were working hard, as were the specialists at the coordination-computing center.

The telemetric and trajectory information, arriving in a continuous stream from aboard the station during the radio communications sessions, was fed into electronic computers where the flight trajectory of the station was defined on the basis of the data from trajectory measurements so that its position at a given moment in time and its flight speed could be determined. The time of arrival of the station on the Moon was determined and the minimum distance for flight around the Moon was ascertained. On the basis of these data, the computer made a calculation of the correction of the trajectory of the station in order to assure that the station would reach the vicinity of the Moon at the set time and at the given distance. As data from trajectory measurements concerning the flight of the station were accumulated during the communications sessions data on trajectory correction were refined.

In addition to solving the ballistic problems, the computer used the incoming telemetric data to put out information on the "condition" of the station and its systems practically instantaneously, or as the engineers at the Coordination-Computer Center say, on a real-time basis. They obtained information about the pressure and temperature in the compartments, in the spherical tanks containing fuel and gas, the temperature in the motor section and on various surfaces of the station. They learned about the operation of the radio equipment in the control system, the electrical power supply and the temperature regulating system.

The computer was also entrusted with transmitting target indications to measuring points, i.e., the programs for the movement of parabolic antenna dishes with respect to the angle of the observer and azimuth during the communications sessions with the station, so that the radio waves would be directed at that point in space where the station would be at that particular time.

In addition to the electronic devices for determining the flight trajectory /19
of the station, a unique optical-television system with high resolution was used, mounted on the high altitude station of the astronomical institute imeni P. K. Shternberg.

The trajectory measurements are complete. It has been ascertained that the control system for the carrier rocket has succeeded in placing the station on the course for the Moon with a high degree of accuracy. The error in injection has turned out to be small, and it will be sufficient to carry out only a single correction with a slight push instead of the planned two to ensure that the station will arrive at the calculated area of circumlunar space.

One can clearly see from the following example what high demands are placed on control systems of modern automatic stations.

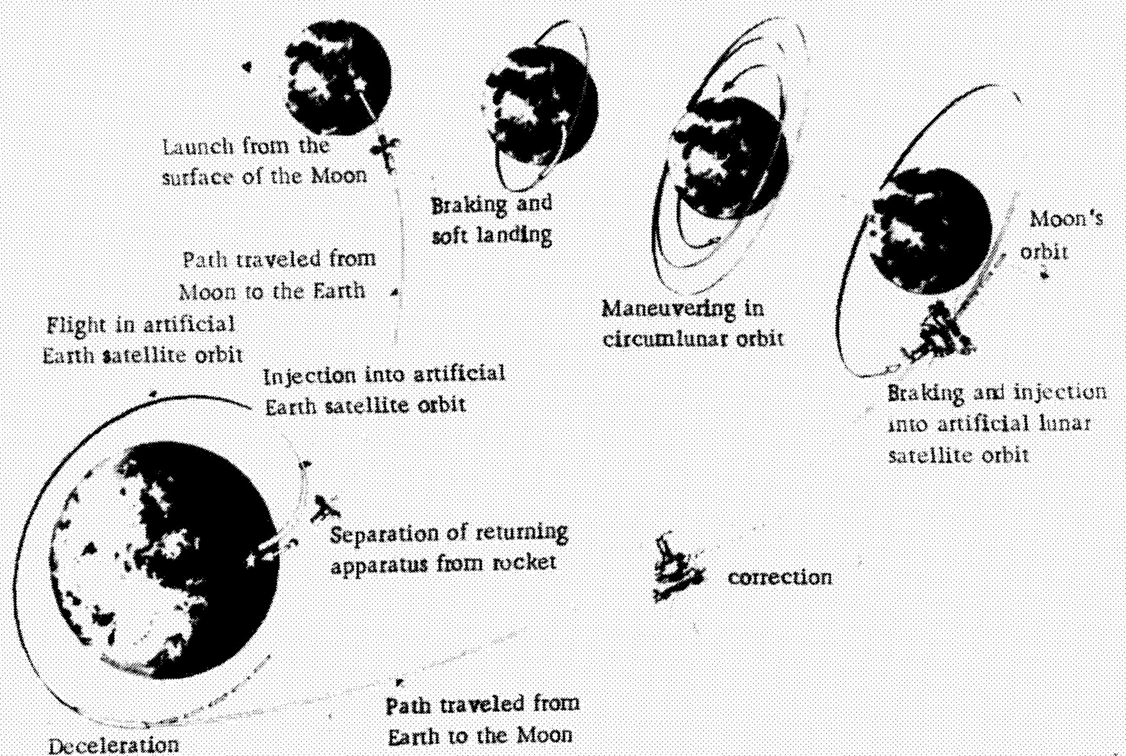


Diagram of the Flight of the "Luna-16" Station.

The speed of the station at the end of operation of the motor unit of the last stage of the carrier rocket is approximately 11,000 m/second. An error of only 1 m a second in velocity will mean an error of up to 300 km at the Moon. An error in the direction of the velocity vector by one minute of angle will lead to an error of up to 100 km at the Moon. It is necessary to ensure that the station lands at the specified point in space near the Moon, at a distance of nearly 100 km from the surface.

On the basis of the results of the trajectory measurements, the original data for performing the correction of the trajectory were calculated at the Coordination-Computer Center — the magnitude and direction of the correcting pulse and the period of activation of the motor unit. During the radio communications sessions, in the form of special codograms, these data were transmitted to the station and "stored" in the memory of the program-timer device of the control system.

Prior to the correction session, the orientation in space session was held. Initially, by means of a control system, and optical sensor and micromotors, orientation was accomplished relative to the Sun, after which the Earth was sought out, whereupon the station carried out a number of programmed revolutions relative to the basic system of axes of the coordinates Sun-station-Earth and assumed the initial position for correction.

On 13 September 1970, at the calculated time, on command from the onboard control system, the motor unit was cut in, giving the "Luna-16" the necessary correcting push.

The gyroscopic instruments in the control system, by means of auxiliary elements (stabilization motors and the main engine mounted in a tilting arrangement) ensured stabilization of the station and maintenance of the set direction of the thrust vector during the operation of the motor unit as the trajectory was corrected.

The trajectory changes, made during the correction session, confirmed the high operational accuracy of the "Luna-16" station's control systems and the motor unit.

The error in sending the station to the Moon with respect to the calculated point was less than 10 km. /20

The next important maneuver which was intended to be performed by the "Luna-16" station in space drew near — the braking maneuver and the insertion of the station into orbit as an artificial satellite of the Moon. Why was this maneuver required? Before this time, automatic stations in the "Luna" series which had terminated their voyages by a "soft" landing, had made a "direct" landing from the trajectory along which they had approached the Moon.

Additional complication of the flight trajectory of the "Luna-16" station was caused by the fact that in the absence of a "direct" landing the direction of movement of the station during the approach to the Moon did not coincide with the direction of the Earth and varied from it by approximately 60°.

In this connection, if the "Luna-16" station had made a direct landing, it would have touched down somewhere at 60° W in Oceanus Procellarum where the "Luna-9" and "Luna-13" had landed. In this situation, a direct launch to Earth without correction would have been simply impossible, so that the station would not have reached the Earth but would have passed to one side of it.

The designers and ballistic experts were faced with the task of getting the rocket back to Earth from the Moon.

There were two ways in which this problem could be solved.

First Method.

To make a "direct" landing, which had been tested and proven... Then to take off from the Moon and enter orbit as a satellite of the Moon, and only then to take off for the Earth. It is necessary to take into account in this connection, however, that before taking off for the Moon it is necessary to ensure orientation of the lauching rocket at least with respect to two astronomical reference points. It is necessary to find them and hold them in the field of vision of optical devices during the operation of the motor unit during takeoff. In addition, it it necessary to determine the magnitude and direction of the thrust vector of the engine during the takeoff from the Moon.

This is the manner in which the American manned spacecraft in the "Apollo" series flew. It is obvious that on the path from the Moon to the Earth it is necessary to make trajectory corrections under these circumstances, since each of the maneuvers listed above involves certain errors which must be corrected.

Consequently, on the return trip from the Moon to the Earth it will be necessary to take along all of the instruments that were used from the flight to the Earth to the Moon but this means that these devices must be mounted on the rocket as it travels from the Moon to the Earth and must be able to operate both on the flight from the Earth to the Moon and on the return trip of the rocket to Earth.

It is obvious that this solution to the problem is rather cumbersome. The greater the mass that we leave behind on the Moon, the less energy expenditure will be required to return the rocket to Earth. Consequently, it is desirable to have the greatest amount of apparatus and instruments combined in the landing stage, which is left behind on the Moon.

Second Method /21

This consists in the following. If the station lands in the region of the lunar surface from which a vertical launch (in the direction opposite to lunar gravity) will ensure a landing on the Earth, it is clear that the problem amounts to constructing a lunar vertical, remembering this direction, maintaining it during the operation of the motor unit during liftoff from the Moon, i.e., to retention of the directional vector of gravity, exact determination of the launch time for landing at the set area on the Earth's surface and giving the rocket the necessary momentum to overcome lunar gravity. Further movement of the rocket occurs under the influence of the overwhelming gravitational pull of the Earth, and the rocket returns to the set region on Earth.

Calculations show that with this method the energy consumption of this experiment is most favorable, inasmuch as the principal mass of the system and instruments remains on the Moon and only the gyroscopic portion of the instruments is located aboard the return rocket.

It is clear that it is only from the orbit of an artificial satellite of the Moon that a highly accurate landing can be made in the region of the Moon which is of interest to scientists (and there are several regions depending on the mutual positions of the Earth and the Moon).

This is why the flight trajectory of the "Luna-16" station differs from the trajectories along which the "Luna-9" and "Lune-13" flew.

Mare Fecunditatis was chosen for the landing of the "Luna-16" station; this structure is located in the eastern hemisphere of the side of the Moon which is visible from the Earth.

No spacecraft had previously landed in Mare Fecunditatis. This region, surrounded by mountains on all sides, is particularly interesting for science because in the opinion of scientists it is a distinctive sea of lava, of comparatively recent origin.

"Luna-16" was approaching the Moon.

By means of ground and onboard radio systems the flight trajectory of the station was determined during the radio communications sessions and the original data were recalculated for carrying out the braking sequence; the position of the station in space, the magnitude of the braking pulse and the time of operation of the motor unit. These data were transmitted in coded form along radio channels to the electronic memory devices in the station control system.

On command from Earth, at a specified time, when the station had reached a given region in space near the Moon, the onboard automatic systems sprang into action and the entire process of the braking sequence proceeded in accordance with the planned program.

Previously, by means of star systems and low-thrust motors, the station had been oriented with respect to the Earth and the Sun and had occupied a strictly determined position in space such that the thrust of the motor assembly during operation of the latter was directed opposite to the direction of flight of the station. After carrying out all of the prepared operations, on 17 October at 0238 Moscow time the motors in the landing stage section were cut in for the second time. As a result of this maneuver, the flight speed of the station was reduced and it went into orbit as an artificial satellite of the Moon with the following parameters:

Height above the surface of the Moon — 110 km; /22

inclination of the orbit to the plane of the lunar equator — 70°;

period of revolution — 1 hour 59 minutes.

The stage of the flight between the Earth and the orbit of the satellite around the Moon had been completed. During this time, the Earth had communicated with "Luna-16" 26 times. During these communication sessions, measurements had been made of the parameters of the trajectory of the movement of the station, the operation of the onboard systems had been checked and two maneuvers had been carried out — correction of the trajectory and braking.

Orbit after Orbit

For 75 hours and 26 minutes, the "Luna-16" automatic station was in orbit as an artificial satellite of the Moon, during which time it completed 41 orbits and travelled approximately 47,000 km. At this stage of the flight the operating rhythm of the ground measuring systems and the Coordination-Computing Center increased markedly and the process of carrying out the radio communications sessions became more complicated. At the same time, while communication with the station during the travel of the latter over the Earth-Moon route could be maintained practically all of the time, when the Moon was in the field of the radio visibility of the measuring devices, now, when the station was hidden behind the Moon in the course of its movements on its orbit, radio communication with it was naturally suspended. In addition, while the receiving-transmitting antennas had followed the daily rotation of the Earth along the Earth-Moon route and the smooth monotonic movement of the station along its trajectory, now the antennas were forced to follow the movement of the Earth, the Moon (during one hour of its movement in orbit, the Moon covers a distance approximately equal to 0.1 of the distance between the Earth and the Moon, i.e., 3,680 km) and rapidly changing with respect to the direction of movement of the station along the orbit of the satellite. The station is located in the zone of visibility of the antenna at 1 limb of the Moon, and disappears behind the other, and the antenna must continually "sweep" in order to maintain communication with the station. It is natural that even for calculating the aiming the computers were required to increase the volume of work considerably.

In addition, the "Luna-16" had to be prepared for landing. It was necessary to solve the complex problem of forming the pre-landing orbit. This orbit must correspond to the optimum conditions of operation of the autonomous systems for the control of the station during the phase of descent and soft landing of the "Luna-16" on the surface in the desired area. For this purpose, maneuvers were /23
carried out in circumlunar orbit on two occasions, 18 and 19 September.

As a result of the first maneuver, the shape of the orbit was changed: from being circular, it became elliptical, with an altitude at perilune (minimum distance from the surface of the Moon) of 15 km and at apolune (maximum distance from the surface of the Moon) of 110 km.

The second maneuver was used to tilt the plane of the orbit slightly. As the result, the inclination of the orbit to the plane of the lunar equator was now 71°, the altitude at apolune was 106 km and the period of rotation was 1 hour and 54 minutes.

To carry out these maneuvers, appropriate ballistic calculations were made taking the following into account: the data of trajectory measurements, the evolution of the orbit of the station under the influence of the field of lunar gravity, the data on insufficiently investigated gravitational anomalies on the Moon — mascons, the influence of the Sun and the Earth on the movement of the station. As a result of these calculations, raw data were obtained for carrying out subsequent maneuvers. During the radio communications sessions, they were transmitted to the station and "stored in the memory" of the device in the control system.

Prior to each maneuver, orientation sessions were held to determine the position of the station with respect to the Sun and the Earth with "holding" of the luminaries in the visual fields of the sensors; programmed rotations of the station relative to the plotted coordinate axes Sun-station-Earth in the original position were carried out.

On two occasions, at a strictly determined time, the motor assembly of the landing stage was cut in and out.

As the trajectory measurements made after correction of the orbit showed, the actual pre-landing orbit practically coincided with the calculated one.

It is necessary to emphasize once again the faultless function of all automatic systems aboard the station. It was not always possible to "interfere" in the control process from Earth, first of all because of the high rate of speed at which the processes took place and secondly because a number of operations were carried out when the station was behind the Moon and could not be reached by terrestrial means.

The station continued its flight in circumlunar orbit. The period of the first, prelanding orbit had begun.

Soft Landing /24

On the 20th of September, at 0606, on command from Earth one of the important stages in the flight of this station commenced — preparation for making a soft landing on the lunar surface.

Now it was necessary to activate devices which had not played a path in the flight heretofore — the apparatus for soft landing, consisting of a Doppler velocity meter, radio altimeter and logical automatic devices.

One can easily imagine how the individuals performing these maneuvers were excited. Indeed, the device was supposed to carry out measurements of changing altitude, the horizontal and vertical components of the velocity of the station during descent, to compare the measured parameters with the calculated ones, to make the correcting signals in the event of the lack of correspondence, and, while strictly maintaining the descent trajectory of the station, to make a soft landing in the given area.

At 0641 the station disappeared behind the Moon and its radio signals could only be picked up from Earth at 0731, when the station came out from behind the southwestern limb of the Moon.

A total of 41 minutes remained before the motor unit would be cut in.

The onboard automatic systems were functioning reliably and smoothly. Telemetry was transmitting information on the state of the station to Earth.

At the coordination-computer center, all attention was directed to the clocks and the brief reports from the loudspeaker. Orientation of the station began. So far everything had gone smoothly, but what would happen now? The time dragged by slowly. Finally the report — "there's the Sun! The luminary in the center of the visual field of the Sun sensor!" A short time passed, and new reports came in: "The Earth is in the center of the visual field of the sensor? The programmed rotation has begun! The programmed rotation has been worked out completely. The station has been brought to the original position for braking."

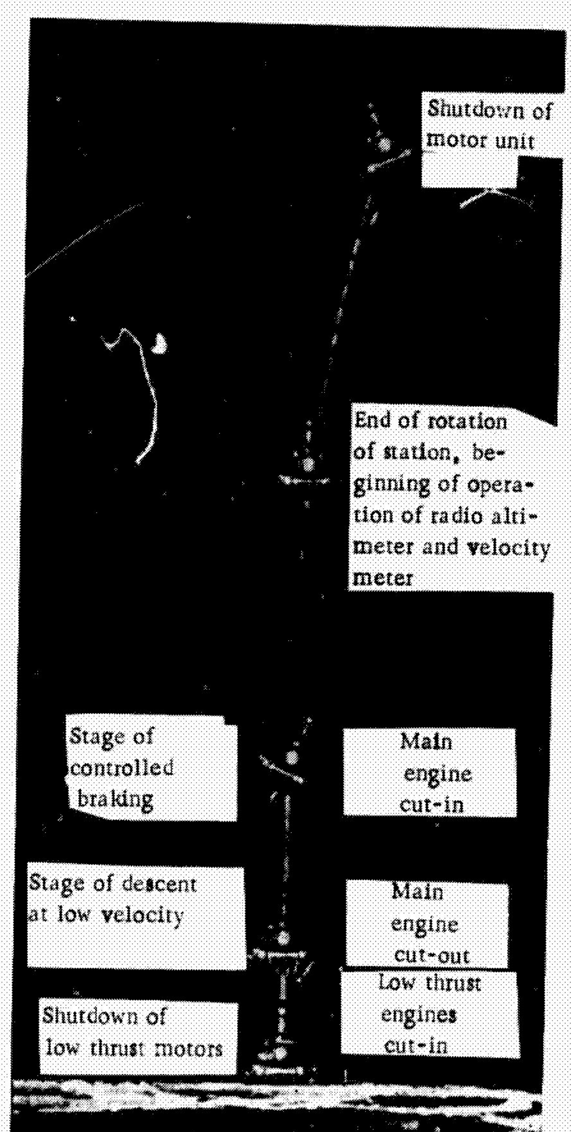


Diagram of Moon Landing of "Luna-16"

Landing Site of Automatic Station.

The sections of the sky in which the apparatus had been located and which ensured flight of the station along the Earth--Moon path and in orbit as a lunar satellite had been discarded, but they had not been used in the descent operations. This is extra weight. Braking it requires expenditure of an additional amount of fuel and the latter is strictly limited. /25

At 0812, when the station was 250 km from the landing site, the main motor assembly was cut in at an altitude of approximately 15 km, so that the velocity dropped to a value which would ensure transition to the descent mode.

During the braking maneuver, the station was in a strictly determined attitude. Therefore, the report of the loudspeaker was frequently repetitous: "roll-pitch-yaw normal!" Particularly these reports as well as another, "pressure in the combustion chamber normal!" answered simultaneously the question as to how braking sequence was preceeding. After functioning for the appointed time, the motor unit was shut down and the station, descending from orbit, began to "fall" along a ballistic trajectory to the Moon. During this time, auxiliary elements in the control system were operating to ensure stabilization of the station in accordance with the program of descent. /26

At an altitude of 600 m from the surface of the Moon, on command from the radio altimeter, the motor assembly was cut in once more. The sequence of precise braking had begun. During this sequence the thrust of the motor assembly was varied as a function of the signals sent by the soft landing apparatus which carefully followed and carried out the set program for the landing. The radio altimeter and Doppler velocity meter functioned flawlessly. The transmitter continuously sent out radio signals in the direction of the Moon which were reflected from its surface and were picked up by the receiving antenna of the station, then fed into a logic device where the measured parameters were compared with the programmed ones and the required control signals were given when there was a lack of agreement. At the 20 meter mark the station had a velocity of approximately 2.5 m per second (while in orbit its velocity had been about 1600 m a second). Upon reaching this altitude, the main motor unit was shut down and 2 low-thrust motors were cut in which ensured the soft landing of the station on the Moon.

On command from the gamma altimeter, these motors were shut down in the immediate vicinity of the lunar surface.

The landing pads of the station contacted the surface, cushioning the shock. The "Luna-16" had completed the first stage of its journey through space. This occurred on the 20th of September 1970 at 0818 Moscow time. The station landed in the region of Mare Fecunditatis, 1-1/2 km from the designated point, with the coordinates 0° 41 ' S and 56° 18 ' E.

The landing site at this time was in the lunar night, and the temperature on the surface reached -120° Celsius.

Before going on to the story of the work of the station on the Moon, we should go into a little more detail regarding the last stage of the landing, the function and design of the landing struts, which reduced the speed of the station to zero, holding it firmly on the lunar surface during the operation of the geological robot and during launching of the return rocket from the Moon to the Earth.

The landing devices of the "Luna-16" station must correspond to the following conditions:

they must operate in the temperature range from -160 to +130° Celsius, in a high vacuum and under the influence of cosmic radiation;

They must keep the station from tipping in the event that it lands on a smooth slope or in an area with uneven relief;

they must allow a soft landing of the station without bouncing.

They must be light, strong, quite simple in design, and what is most impor- /27
tant, fail-safe.

In order to cushion the shock against the surface of the Moon (the mass of the station is 1,880 kg), it is necessary to have movable shock absorbing devices, for example, like those on modern aircraft. However, there are several "buts", which prevent aircraft design from being employed.

The first is the fact that fluid is used as a shock absorbing agent in aircraft shock absorbers. But what fluid can retain its properties and especially its viscosity in a temperature range from -160 to +130° Celsius.

The second is that a gap must be provided to ensure movement of the shock absorbing mechanism between the internal and external sections of the movable connection, but the gap must be minimal, with a complex system of glands, otherwise all of the fluid would simply evaporate in the vacuum of space which is 10^{-14} mm Hg.

It is a very difficult problem to create a minimum gap with temperature drops of approximately 300° Celsius not to mention glands that are designed for working at such high vacuum.

Indeed, all kinds of rubber and plastic substitutes lose their elasticity at such temperatures and vacuums and adhere firmly to the metal, so that a fixed connection is obtained instead of a movable one. It is necessary to take into account that metals themselves are welded together in a vacuum. Let us assume that the designers have been able to overcome these difficulties; however, the design is then quite complex and heavy. In addition, its reliability is extremely low.

It is clear from the above that the problem of developing a landing device was not as simple as it seemed at first glance.

The designers searched for a long time. They made many tests. Failures and successes. Finally, they found a solution. It was simple and reliable.

Imagine two tubes (struts), one inside the other and linked by a metal spring, serving for expansion (when one strut is pushed into the other). This design has been known for a long time, but it has one shortcoming — the spring works both during compression and expansion, i.e., the expansion cycle is followed by a relief of stress, followed in turn by the process of compression, and this kind of a mechanical movable system will go into oscillation. The "Luna-16" station, on the other hand, must make a soft landing without bouncing.

Pennants Mounted on the "Luna-16" Automatic Station.

The clever designers thought up an original solution in which the spring was replaced by the expansion of a metal rod, which possesses considerable viscosity. /28

Then on each "leg" of the landing platform, and there were four of them on the station, they mounted a strut composed of two movable cubes, connected by the spring and rod.

Each "leg" was fitted with a "galosh" in the form of a large plate. The greater the area of contact with the ground, the lower the specific load per cm of lunar surface, and the greater the likelihood that the station would not tip over on the porous friable surface.

At the moment of landing, the energy of the impact would be taken up by the spring and rod, they would expand, and the station would land softly due to the residual deformation of the rod.

Thus, a solution was found!

All of this seems quite simple. First of all, however, the solution had to be found and in the second place, in order for the solution to be made a reality it was necessary to perform a great many experiments and to prepare the necessary chemical composition of the material of the rod, as well as to carry out tests of the landing platform. On the Moon, the station is not awaited by a flat surface, but one which is broken by craters and fissures, covered with rocks, and the station must land softly under these conditions.

A model of the station with "lunar weight" at the lunodrome on Earth is dropped on a concrete slab, on sand, on rocks, and on the sloping surface. It appears unlikely that such a delicate design would remain intact after such tests, but it remains not only intact but in working condition.

The Automatic Geologist at Work

Forty-five minutes have passed since touchdown. The controllers, engineers, designers, and scientists are still excited after watching the soft landing sequence of the "Luna-16" at the measurement points and at the Coordination-Computer Center, and a continuous stream of telemetric data is coming from the station, reporting on its position on the lunar surface, the condition of the onboard systems, and their readiness for carrying out subsequent operations.

Now the station turns into a geological drilling rig, with the landing platform as its boom.

In accordance with radio commands from Earth, the soil-collecting apparatus was activated and the cameras of the telephotometers were switched on, to ensure transmission to Earth of data showing pictures of the place from which the lunar soil was collected. New commands were given. A panel opened which had carefully protected the soil-collecting device during the flight of the station and an arm with a drill on the end was raised to a vertical position by one of the drives. Then a second drive turned it around its vertical axis through 180°.

Before the arm comes down, an automatic device functions to open up a cover on the drill.

When it contacts the surface of the Moon, a contact sensor operates and a telemetric signal transmits this news to Earth.

Contact! The drill is ready to work! On command from the operator, drive mechanisms were activated, one to rotate the core drill and the other to move it downward into the depth of the lunar soil.

20 September 1970, at 0903 Moscow time, the device controlled from Earth first started working on the Moon. The process of collecting soil had begun. Measurements of the density of the lunar soil and the rate of penetration of the drill into the lunar rock were made.

At 0910, when the drill was submerged to a depth of 350 mm, the device ceased operation and a drive returned the drill bit from the lunar soil into the housing of the drill.

The arm drive was again activated; it was raised to a vertical position, turned through 180° around its axis, and the drill was brought to the receiving opening of the hermetic container in the return apparatus.

The next command in sequence was given and the drill containing particles of the Moon moved into the container. The arm containing the drill housing moved away from the receiving opening after which a special automatic device hermetically sealed the opening in the return apparatus.

Hardly two hours had passed since the "Luna-16" station had landed, and an important part of the program of its flight had already been completed successfully.

The lunar soil had been collected!

It is not difficult to imagine the mood of those who had built the soil-collecting device. Behind them were the long searches for the design, incorporation of the design in metal, the testing and the trial.

And all of this was for the first time. None of them had ever designed an automatic lunar geologist. What should the soil-collecting device be like? Like a terrestrial excavator with a single bucket, or like a rotary multiple-

-bucket device with a helical feed mechanism? Or did it have to be a drill rig like that which is used by geologists on Earth to collect soil samples? And the soil itself might be different — from shifting sand to solid basalt, and it is necessary that the collection be made without disturbing the structure of the soil sample with regard to depth.

This immediately ruled out the excavator design. In the first place, it could not collect hard rocks such as basalt; secondly, it would disturb the structure of soft rocks and in the third place the conveying and packing of the soil from the scoop in the container would be a difficult task.

There remained the core drill — a tube with a cutting edge at the end.

It had a lot of problems:. while it would drill well through hard rocks and hold them, it would drill easily through soft ones but would not be able to hold them.

To solve the basic problem (holding of the soil) the "Luna-16" station also carried out temperature measurements of the design elements and the level of radiation at the lunar surface, whose results were transmitted to Earth.

Liftcff from the Moon and the Way Back to Earth

All of the operations involved in the collection of this soil were completed, and the necessary tests of the apparatus and the systems of the station had been carried out. The computers at the Center for Remote Cosmic Communications transmitted all necessary data concerning launch time and the necessary impulse which would make possible the return to Earth of the first lunar automatic rocket.

On radio command from Earth, the raw data were "stored" in the "memory" (in an electronic computer) of the control system of the "Moon-Earth" rocket.

Now the landing platform of the "Luna-16" station turned into an automatic device which was preparing and ensuring the launch of the "Moon-Earth" rocket.

The command was given. At this moment, the success of the flight with the function of the operation of the automatic control system and the motor assembly.

From aboard the rocket, radio signals reported to Earth step-by-step regarding the processing of the launch programming.

The directors of the flight, the head designer, the engineers and designers, scientists, controllers — all were filled with anxiety and expectation.

This was understandable: an event was going to take place which was unprecedented in cosmonautics. For the first time, an automatic rocket would be launched to Earth from another heavenly body to serve the will of man, after it had carried out the necessary research program.

Finally, the triumphant and excited words sounded in the loudspeaker: we have ignition! The engines are go. Liftoff! This took place on 21 September 1970 at 1043 Moscow time, 26 hours and 25 minutes after the "Luna-16" station had landed on the Moon.

Let's have a look at the return rocket. Its appearance is strange. Where is the strong aerodynamically designed shell of the rocket, tipped with a conical nose, the shape with which we are so familiar?

Here everything is on view! The return apparatus and the instrument package, the engine section with its spherical tanks in which the fuel and antennas are contained. If such a rocket were to take off on Earth, it would be destroyed in an instant by the rushing air.

On the Moon, however, which lacks an atmosphere, the housing of the rocket and the envelope are not required; they only constitute extra mass. /33

The landing platform of the "Luna-16" station, after the return rocket was launched, remained on the surface of the Moon and continued to make temperature and radiation measurements according to plan.

But what of the rocket, the automatic mechanisms were working correctly. Upon reaching the necessary velocity of 0708 m a second, the engines shut down and the rocket together with all the apparatus onboard heads for Earth.

The flight goes on. The onboard radio system starts working at a frequency of 183.6 MHz, in order to ensure continuous radio communication with the Earth during the 3-day flight of the rocket and to carry out trajectory measurements to zero in on the landing site on Earth for the returning apparatus.

During the flight, the temperature regulation system of the returning apparatus operated reliably, providing the correct temperature conditions in the compartments.

The functioning of the control systems, radio communication, temperature regulation, etc., would have been impossible without the reliable functioning of the power supply system. This system also worked flawlessly.

As a result of the precisely performed operations as the rocket took off from the Moon, the flawless operation of the engines, the control system and other apparatus, a spacecraft returned to Earth for the first time at the appointed site without requiring any corrections to the trajectory!

This happened early in the morning of 24 September 1970.

Traveling at a velocity somewhat greater than 11 km a second, the rocket containing the returning apparatus approached the Earth which it had left 12 days previously.

Three hours and 20 minutes prior to the entrance of a rocket together with the returning apparatus into the dense layers of the atmosphere, the percussion bolts were exploded on command from Earth, the returning apparatus was separated from the steel bands, moved away from the instrument package of the rocket and continued the rest of the flight alone.

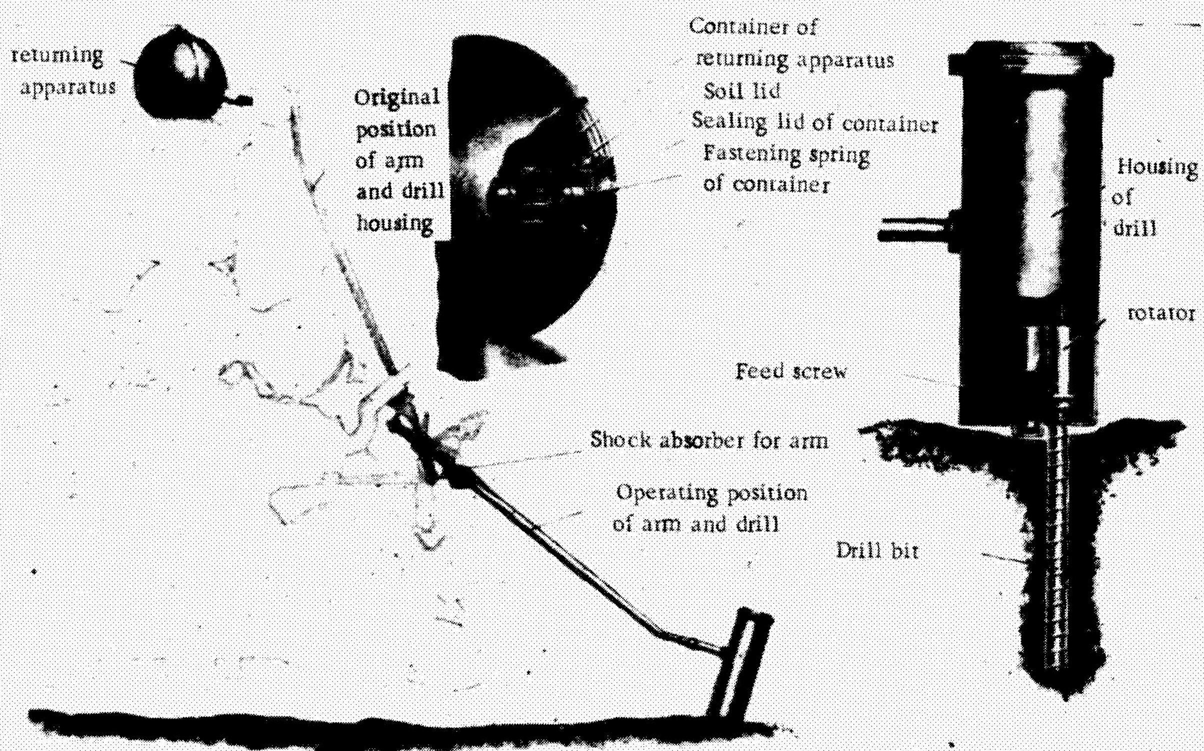
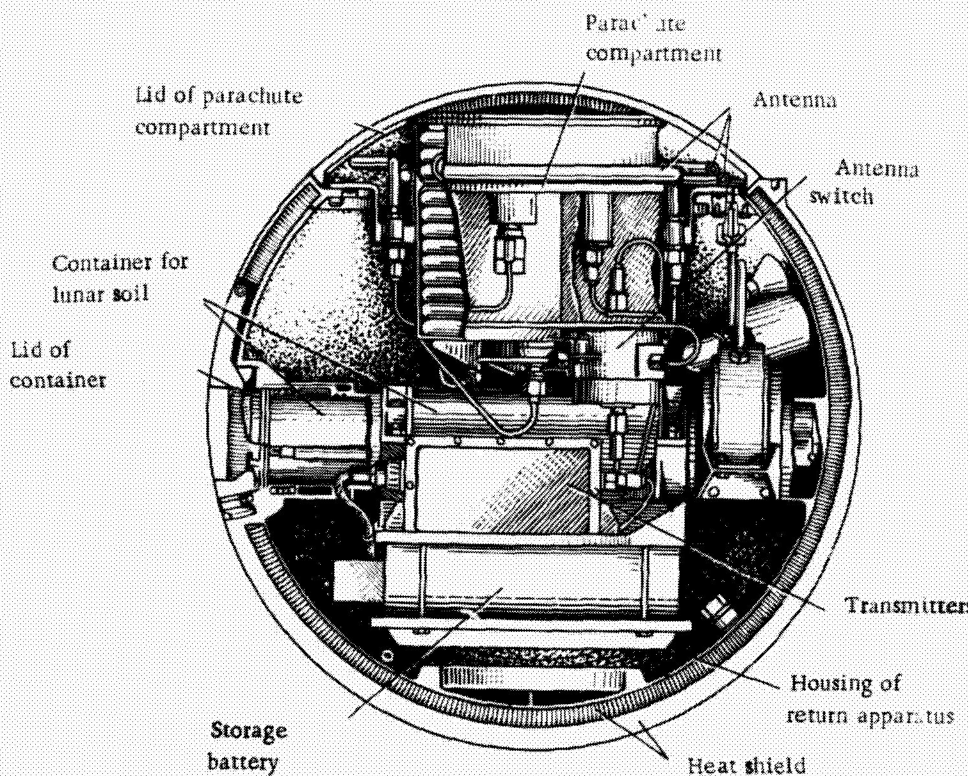


Diagram of Soil-Collecting Device of the "Luna-16" Automatic Station.

Return to Earth

The final stage of the flight had arrived. The builders of the returning apparatus were more agitated and excited than anyone else. This is easy to understand; now the results of the entire experiment depended upon the reliability of the design of the apparatus, the functioning of the automatic systems, the parachute system, the radio direction finders. All of the stages of the development of the returning apparatus and its systems were etched in their memories. How they built and "fired" in a plasma flame the heat-resistant "jacket" of the returning apparatus, how many dozens of times they threw it out /34 of supersonic aircraft down to Earth, to land on rocks, sand, in the woods and in the water. Indeed, it does not burn in fire and it does not sink in water! It will not freeze in the deep cold of outer space! In fact, it is like one of those childrens' dolls which always returns to a standing position when knocked over: no matter how it lies on the ground, it always adopts a position such that at least one of the three transmitting antennas is directed upward to allow transmission of signals.



Parts Aboard the Return Apparatus of the "Luna-16" Automatic Station.

And what have they not done with the parachute system! After packing it in the container, it was shaken on a vibrating stand, roasted in the temperature chamber, irradiated and then subjected to mechanical tests (for strength), and still later was subjected to flight tests.

The flexible whip antennas in sectional form became so entangled with the shrouds and canopy of the parachute that it seems that they could not unfold at all and there would be no signal. But there was a signal!

And it was only after these and many other tests that the systems of the returning apparatus got the go-ahead.

Now the Earth itself will test them!

The Earth greeted its messenger with very "warm" and "firm" embraces at 0810 on 24 September 1970. When the returning apparatus entered the atmosphere of the Earth, the aerodynamic heating caused the temperature in the nose section of the apparatus to reach 10,000° in the boundary layer and aerodynamic braking meant that the g-forces acting on the elements of the design, the instruments and the system reached 350 units, i.e., each part of the apparatus increased its mass by a factor of 350!

Landing of Return Package of "Luna-16" Space Station During Flight Tests. /35

Since the returning apparatus had been designed so that the center of gravity was ahead of the center of pressure, the oncoming flow of air turned the front part which had the greatest amount of heat shielding into the oncoming flow, and the damping device smoothed out the oscillations of the apparatus, thereby ensuring the most favorable conditions for entry and braking in the atmosphere.

During the increase in g-forces, when a certain level was reached, the programming-timing mechanical device turned on automatically and so did the command sensors of g-forces and pressure. Then, after passing through the peak of maximum g-force and temperature, the g-force sensor sent out a signal to release the wings of the parachute section.

At a descent velocity of 300 m a second, the braking chute opened. The command to open it could be given in any one of three ways: either by the g-force sensor, the pressure sensor, or the programming-timing apparatus.

During descent under the braking chute, the velocity of the landing apparatus decreased to a value which allowed the main chute to open. Beforehand, according to a signal from the pressure sensor, the braking chute was released, /36 the main chute opened and 3 flexible antennas of the direction-finding radio transmitter unfolded. This took place at an altitude of 11 km above the ground.

Practically simultaneously with the unfolding of the antennas, the direction finding transmitter began to operate, sending out its signal into the ether: **"Here I am! Here I am!"**

At 0814 Moscow time this signal was picked up by aircraft, helicopters and ground facilities of the search group, which concentrated in the planned area for the landing of the returning apparatus. Subsequent descent of the apparatus to the ground was observed from a helicopter.

At 0825, the returning apparatus landed on the ground 80 km to the southeast of the city of Dzhezkazgan, not very far away from the point at which the carrier rocket which had sent the "Luna-16" station to the Moon had lifted off.

The flight of the "Luna-16" automatic station attracted the attention of scientists all over the world. It is interesting to note the evaluation which United States scientists made regarding this experiment. The USA has its own national program for investigation of space which is aimed, in particular, at studying the Moon by means of manned spacecraft in the "Apollo" program.

Here is the statement of a famous American scientist, the head of the Department of Astronomy at the California Institute of Technology, Doctor D. Greenstein, who is also the head of the Mount Wilson and Palomar Observatories.

"...The first unmanned flight to the Moon and back, made by the "Luna-16" spacecraft, is an amazing achievement of science and technology. The horizons opened up by this flight are very promising. We scientists are excited by the courage of the Soviet cosmonauts and the American astronauts, but from the practical point of view we are more interested in the efficiency of automatic stations like the "Luna-16". Their advantages are obvious – they are cheaper and do not require risking human beings. The Moon is the heavenly body closest to us. But imagine flights to more distant planets. In order to be able to bring back samples of rock from there by using human hands, it might possibly require the expenditure of the lion's share of a national budget of some country. The way out of the financial deadend – some deadends are not strange to science – consists in automatic stations controlled from Earth. The first step which you have taken is an inspiration!..."

What the Lunar Rock Had to Say About Itself /37

After landing, the returning apparatus was subjected to a careful check at the landing site. This examination revealed that the apparatus had successfully withstood the flight conditions. It was decided to bring it to Moscow and to send the container with the lunar soil to the Academy of Sciences of the USSR for study.

After removing the container of lunar material from the apparatus, it was subjected to dosimetric measurements and carefully sterilized. As the dosimetric studies revealed, there was no significant increase in the intensity of gamma radiation from the lunar material relative to the intensity of gamma radiation from terrestrial rocks containing small amounts of naturally radioactive elements. This facilitated working with the lunar material. Then the container was placed in a special vacuum receiving chamber, made of stainless steel. This chamber was equipped with devices and instruments that made it possible to open the container of lunar material, subject it to a preliminary testing and repack it in special hermetically sealed containers for subsequent detailed investigation.

Externally the chamber with its portholes made of safety glass were somewhat reminiscent of a device for making deep dives. It was equipped with a special hermetically sealed airlock, making it possible to take out containers with samples of lunar material and to put in necessary instruments and tools.

Beneath the portholes, in special openings, rubber gloves had been fastened which made it possible for the operator to open the container, take out the drill with lunar substance inside, unload the lunar material into containers, and to carry out other necessary operations.

After placing the container in the chamber and fastening it down, a high vacuum was produced by means of pumps. This was done so that the possibility of an interaction between lunar material and active elements in substances in the terrestrial atmosphere such as oxygen, water and the products of sterilization, which could enter into a chemical reaction with the lunar substance and irreversibly change its properties, was excluded.

Then the chamber was filled to atmospheric pressure with an inert gas (helium).

With this, the preliminary operations preceding the opening of the container and the extraction of the lunar soil were complete.

Using the tools and devices located in the chamber, the operator opened the container and took out the drill with the lunar substance inside. The lunar dust was grey, fine, but covered the shiny surface of the drill with a dense coating. A great deal of it had fallen off the surface of the drill in the container; this dust was assigned a particular place in the chamber.

The major part of the lunar soil was taken out of the drill and placed in an examination trough so as to retain the distribution of the lunar substance as collected at different depths by the sampler. /38

So here was the "earth" from the Moon, collected by the "Luna-16" station from the region of Mare Fecunditatis. Most of its mass was composed of fine grained mineral particles of a grey color. When a ray of light struck it, it suddenly changed color: it changed from grey to brown, even slightly reddish, and when the light struck it from another angle greenish flashes appeared on it.

That portion of the sample which was taken from a depth of 350 mm clearly showed crystals measuring several mm, clearly sparkling at their edges.

All of the operations involved in opening the container, taking out the drill and lunar substance and the lunar substance itself were repeatedly photographed. This fact is not only of scientific importance but of considerable historical value as well.

Thus, the lunar material was prepared for studies to be performed at the laboratories and institutes of the Academy of Science of the USSR and the specialized institutes of other ministries and departments.

The toxicological and biological checks were over. There is no danger, the scientist said, the quarantine is lifted; it is all right to proceed with further study of the lunar soil. This is what was said about the first results of scientific studies of lunar rock at a press conference held on 28 October 1970 at the Moscow House of Scientists, by Academican A. P. Vinogradov.

"...A sample of lunar soil has been brought back to Earth from the north-eastern part of Mare Fecunditatis, located approximately 100 km west of the crater Webb."

Mare Fecunditatis is a plain with low walls of folded type running across it. Its shores do not have a round, mountainous rim. There are no large craters with systems of rays in this region. The soil sample was taken from /39 an area which is located approximately 900 km to the east of the landing site of the "Apollo 11" and is characterized as a new region of the Mare surface of the Moon. In collecting the soil, the drill relatively easily penetrated the friable coverning of the Moon — regolith — to a depth of 300 mm. The regolith is any friable surface material of a planet regardless of the conditions of its formation.

As the telemetric data showed, at a depth of 300 mm the drill either struck hard rock or an individual large fragment of a rock, and further penetration of the drill did not exceed 50 mm. The total depth of penetration of the drill was 350 mm, as was planned for the experiment. When opened at the laboratory back on Earth, the drill turned out to be completely filled with granular lunar soil (regolith).

The lunar soil that was transferred to the receiving tray had no visible stratification and appeared to be uniform throughout. Only a small portion of the soil at a depth of about 350 mm was made up of material with larger grains. The total mass of the column of soil returned to Earth by the "Luna-16" station, amounted to a little more than 100 g.

On the whole, the soil consists of dark grey (blackish) powder with various sizes of grains, with predominance of fine grained fractions having an average grain size of about 0.08-0.1 mm, which could be shaped easily and adhered in individual friable clumps. This characteristic definitely distinguishes it from terrestrial unstructured dust. In terms of this characteristic the lunar soil is more reminiscent of wet sand or the lump-like structure of our soil.

All impressions were received and preserved in the lunar soil. Thanks to the presence of considerable adhesive forces, soil that was poured around a glass rod mounted vertically did not fall apart when the latter was removed. Regardless of its good adhesion, it flows readily through a sieve. Lunar soil possesses a high capacity for electrification, which is manifested for example by the adhesion of its particles to surfaces made of lucite, teflon, etc.

It proved difficult to visually estimate the brightness of the lunar soil because it changed markedly depending on the mutual positions of the eye of the observer and the source of the light. This characteristic of lunar soil is expressed in its ability to scatter light nonuniformly in different directions as a function of the wavelength of the light and the angle of incidence. The most important thing is this phenomenon is the structure of the surface soil and the reflectivity of the vitreous grains which go to make it up. The normal albedo (ratio of incidence light flux to the reflected portion) for visible light in the case of lunar soil was 10.7%, which is close to the values of terrestrial observations of the albedo of Mare Fecunditatus.

The color of the soil frequently lead to conflicting opinions on the part of observers: some felt that it was greenish, others thought it was brownish and still others thought it was dark red. This is explained by the fact that /40 a greenish hue is observed at viewing angles close to vertical due to the above mentioned characteristic of the reflective and scattering characteristics of lunar soil. Increasing the viewing angle leads to the development of a reddish brown hue. Differences in perception of color increase with increasing angle of incidence of the light on the surface of the soil. It is probable that the visual impression is created due to the presence of both green and brown grains of glasses and minerals in the soil.

Lunar Soil Returned To Earth by the "Luna-16" Automatic Station.

The graininess of the soil increases with depth. On the basis of the measurements of the size of the particles making up the lunar soil, the latter can be divided into 5 zones.

The first zone extends down 5 cm, and is the most friable; it consists of fine grained material with a low content of coarse fractions, and determines the principal optical characteristics of the lunar surface. It has a volume weight of up to 0.8 g per cm^3.

The second zone extends down to 15 cm and also consists of fine grain material (somewhat larger in size) with a small content of coarse fractions.

The third and fourth zones extend down to a depth of 33 cm, and are composed of material with different grain sizes, including lumps of rock and other particles larger than 3 mm in diameter.

The fifth zone is characterized by the presence of large grained material. It is located at a depth of 33 to 35 cm.

Below this, obviously, was solid rock or a piece of it. As a result of the tests that were conducted it was established that the average volume weight of the soil in its natural occurrence with depth is 1.2 g per cm^3, and after compaction it is 1.8 g per cm^3, consequently the porosity of lunar soil at depths up to 35 cm may be estimated at 50 to 60%. /41

In a microscopic study, among the particles of lunar soil there could also be seen a number of different shapes, some of which differed markedly from terrestrial formations. Two basic kinds of shapes can be distinguished: particles of primary magmatic rock (basalt type) and particles that have undergone considerable changes on the surface of the Moon. The first are characterized by their protogenic nature, observed on Earth only in freshly crushed samples of unchanged rocks. They have angular shapes and have no traces of rolling.

The second type is characterized by centered particles of a complex, fantastic shape, frequently vitrified from the surface, and also spherical ones with melted formations of hardened droplets — they have a glassy and metallic sheen, similar to the "space spheres" found on Earth.

The following were found and studied in the lunar soil:

basalt rocks: they make up about 25% of all the large grain fractions The principal materials of these rocks are plagioclases, pyroxenes, ilmenites and olivines. Their percentage in various particles varies considerably.

Feldspathic rock: they are found in small amounts and constitute white crystalline grains. A number of investigators consider them to be the continental rock of the Moon, scattered to considerable distances as the result of volcanic activity and the impacts of meteorites.

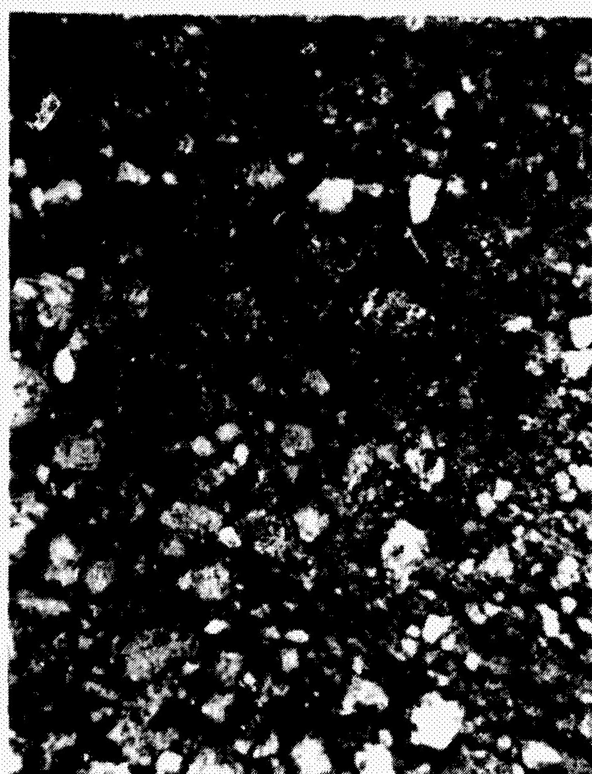
Grains of Individual Minerals, Which Consist of Plagioclase, Olivine, Pyroxene, Ilmenite, i.e., of the Principal Minerals of the Basalt Rocks

Their numbers are low in the large fractions, but increase with decreasing particle size.

Solidified Spherical Droplets and Similar Formations

Transparent and nontransparent glassy spheres are found, as well as pear-shaped and dumbbell-shaped drops of various colors: cloudy white, greenish and yellowish brown, sometimes hollow. Their sheen varies from glassy to metallic. They are found in the greatest numbers in small fractions. Their process of formation occurs at temperatures that are considerably greater than the melting point of rocks and meteorites.

The dimensions of these glassy spheres are usually less than 20 microns, but spheres of larger size are also found. Their specific weight is 2.6 to 3.1 g per cm^3. The index of refraction varies from 1.46 to 1.75. They make up a total of 0.01% of all of the soil.



Particles of Rock in Lunar Regolith (Enlarged).

Breccias were formed as the result of compaction of finely crushed material of the regolith and contain all of its component parts in differ- /42
ent proportions, including particles of primary magmatic rock. Some of the breccias have a smooth shape, slight compaction and are readily broken yp by mechanical forces. A characteristic feature of many breccias is their magnetic properties. Breccias make up 40% of all of the particles.

Clinkers constitute the small centered particles which form very complex irregular branched forms. Like the breccia, all types of particles go to make them up — components of the regolith. The number of clinkers is 15 to 20% of the total number of particles. They are found practically only in large fractions.

The existence of breccia and clinker indicates that a process of merging of particles is taking place on the lunar surface at the same time as processes of crushing and grinding of rock.

Glasses, Vitrified and Slag Particles

More than half of all of the particles of lunar rock were melted or slagged to varying degrees on one or more sides. Glasses of the dark brown and black color predominate. Both bubbling slag formation and smooth glassy vitrification are encountered.

This typical lunar melting can occur only during instantaneous heating of a particle that is cold all the way through.

In addition, glass of volcanic origin is found (volcanic ash) — these are brown, large-bubbled thoroughly molten grains with a characteristic conchoidal fracture, which could be formed during the crushing of comparatively large masses of molten rock. The total amount of glass of this kind is small.

Particles of metallic iron are rarely found both in the form of individual lumps which are evidently remains of iron meteorites and in the form of small inclusions in breccia and clinker. The govern the basic magnetic properties of the lunar regolith.

As a result of mechanical, electromagnetic and thermophysical studies of the lunar soil it was found for example that the specific thermal capacity of the soil is not a function of the density of the fill and generally corresponds to terrestrial rocks, but the thermal conductivity is characterized by extremely low values, much lower than the very best heat insulating materials on Earth.

In terms of its chemical composition, the soil material is rock of the basalt type, in which approximately 70 chemical elements have been found.

As far back as 1966, on the basis of data that were obtained by the "Luna-10" station it was determined that the surface rocks of the Moon were made of basalt.

In the table below, we have listed some data on the composition of the rocks that were returned to Earth by the "Luna-16" station, in comparison with data from samples that were collected by the "Apollo-11" and "Apollo-12" missions (weight per cent).

Chemical composition of compounds	Fine fraction			Basalt Rock		
	"Luna-16"	"Apollo-11"	"Apollo-12"	"Luna-16"	"Apollo-11"	"Apollo-12"
SiO_2	43,8	40,77	40	41,7	42,45	42
TiO_2	[illegible],9	7,92	3,7	3,39	7,24	3,1
Al_2O_3	13,65	11,82	11,2	15,33	13,83	14
FeO	19,35	19,79	21,30	16,64	16,49	17
MgO	7,05	7,74	11,7	8,78	7,97	12
CaO	10,4	10,58	10,70	12,49	11,96	10
Na_2O	0,38	0,51	0,95	0,34	0,41	0,40
K_2O	0,15	0,29	0,065	0,10	0,13	0,18
MnO	0,2	0,22	0,26	0,21	0,20	0,25
Cr_2O_3	0,28	0,33	0,55	0,28	0,27	0,41
ZrO_2	0,04	0,1	0,023	0,013	0,05	0,09

Commas indicate decimal points.

It is clear from the table that there is a tendency to a decrease in the content of a number of elements in the fine fraction in comparison with the dense rock (FeO, TiO_2, etc.).

Others show a significant increase in the fine fraction, especially Al_2O_3, ThU, etc. The content of Th and U is of the same order as in the "Apollo-11" and "Apollo-12" samples. Th is on the order of 10^{-4} and U is on the order of 10^{-5}%. Regardless of the fact that the place where the "Luna-16" samples were collected is 900 km distance from the place where the "Apollo-11" samples were found, in Mare Tranquillitatis, they differ markedly from the latter in having a much lower content of TiO_2, ZrO_2, rare Earth elements and certain others and in a higher content of FeO. It is interesting that the "Luna-16" and "Apollo-11" samples have the same high content in the fine fractions of the cosmogenic inert gases He, Ne, Ar, Xe, Kr, in contrast to the "Apollo-12" samples. In addition, as we can see from the table, in their general composition the "Luna-16" samples are similar to the samples of rock collected by "Apollo-12" in Oceanus Procellarum about 2,500 km distance from the landing site of the "Luna-16". In analyzing the results that were obtained, Academician Vinogradov feels that the crystalline rocks which make up the surface of the lunar Maria are of a single basalt type but some differ in their contents of different chemical elements and their composition approaches the composition of primitive basalts on Earth.

Rocks of basalt type are formed from the most readily molten parts during the melting of the inner substance of a planet and its ejection onto the surface. The lunar Maria are planes which were flooded some time ago by volcanic lava.

In view of the fact that the basalt on the Moon and Earth is very similar in terms of its chemical composition, we can assume that on the Moon, on the Earth and probably on other planets as well which are of the terrestrial type the formation of rocks has proceeded in an analogous fashion and their destruction is proceeding under the influence of various factors.

Thus, the substance of the lava Maria is obviously subject to lunar crushing — "lunar erosion" under the influence of the solar wind, corpuscular cosmic radiation, impacts of meteorites, considerable variations in temperature at the surface, and the vacuum of space. At the same time as erosion, crushing /44
of rocks on Earth proceeds, as we know, under the influence mainly of carbon dioxide, moisture, temperature variations and under the influence of living organisms.

In order to understand the processes that take place on the surface, it is necessary to determine what factors are the most important with regard to the process of the breakup of lunar rock.

Impacts of meteorites and micrometeorites can breakup the surface rocks of the moon to a large extent, mixing all of the friable material. But it is necessary to find sufficient signs of these meteorites in the lunar soil. Corpuscular radiation definitely affects the lunar rocks, so that they exhibit radioactivity, etc., but it does not penetrate far into the rock. Finally, it may be that volcanic eruptions on the Moon, in the vacuum of space, produce crushing processes and the formation of ash-like substances. But this is only an assumption, which requires proof.

The study of lunar rocks and processes in which they participate makes it possible to approach an understanding of the geological phenomena which took place on the Earth during the period of its early existence, which may open up a new page in geology — the search for valuable resources.

Direct study of the Moon has only begun; all of the work still lies ahead. Automatic geologists can help man to solve this and other problems.

In the laboratories of the institutes, the study of the lunar material collected by the "Luna-16" station is going on still. A twin of the "Luna-16" station has been given an honored station in the "Space" Pavilion at the Exhibition of the Achievements of the National Economy of the USSR. The "Luna-16" station belongs to history. Together with the station, on a special stand, visitors to the exhibition can now see lunar rocks which have become part of the Earth! The Central Committee of the Communist Party of the Soviet Union, the Presidium of the Supreme Soviet of the USSR and the Soviet of Ministers of the USSR in their statement to the scientists, designers, engineers, technicians, workers and all the collectives who took part in building the automatic "Luna-16" station and carried out the program of its flight, gave the following opinion of their work: "Our land, Soviet science and technology, have achieved a new and outstanding success in research and conquest of outer space...

"...For the first time in the history of the conquest of space, a theoretically new problem has been solved, the flight of an automatic apparatus to another celestial body, collection of samples of its soil, and return of the latter to Earth...

"...The new achievements of Soviet science and technology in the construction of automatic space stations was made possible by the inspired labor of the working class, the Soviet scientific-technical intelligentsia. This victory is a particularly joyous one because it took place in the Lenin Jubilee Year, /45
during the period of preparation for the 24th Congress of the Communist Party of the Soviet Union."

The party and the government gave a high rating to the labor of the builders of the rocket and space complex and the individual who made possible the flight of the "Luna-16" station and the recovery of the lunar soil with its return to Earth.

The Presidium of the Supreme Soviet of the USSR awarded the title of Hero of Socialist Labor on the group of designers and workers and conferred orders and medals of the USSR on a great many workers who were most outstanding with respect to the construction and launching of the "Luna-16" automatic space station.

In accordance with the decree of the Central Committee of the Communist Party of the Soviet Union and the Soviet of Ministers of the USSR, the Lenin Prize and two state prizes of the USSR in the field of science and technology were awarded to the scientists, designers, engineers and workers for the construction of the rocket-space complex which made possible the flight of the automatic "Luna-16" station and the bringing back of lunar soil to Earth.

Those who took part in the construction of the "Luna-16" station and made its flight possible were exhorted by the Central Committee of the Communist Party of the Soviet Union, the Presidium of the Supreme Soviet of the USSR, the Soviet government and the entire Soviet people to multiply their efforts in carrying out new tasks for the further conquest of space in the name of our great Motherland and in the interest of all mankind!

ACROSS THE EXPANSES OF THE MOON

/46

The Moon Walker

Little more than a month had gone by after that famous day when a sample of lunar soil collected on the Moon by an automatic space geologist had been brought back to Earth in a hermetically sealed container by the recovery package of the "Luna-16" station.

And again the world was astounded and amazed by an outstanding new achievement of Soviet cosmonautics!

The Soviet automatic space crawler, "Lunokhod-1", brought to the Moon by the "Luna-17" automatic station on 17 November 1970 at 0928 Moscow time, set down its wheels for the first time on the lunar surface in the vicinity of Mare Imbrium! Soviet science had received from the engineers and designers, workers and controllers, the builders of the "Luna-17" station, an effective new automatic device for studying the Moon.

The "Lunokhod"

In September 1970, when the "Luna-16" automatic station had completed its historic flight, the engineers, designers, and workers were carefully preparing for the flight of a new spacecraft at the launch site.

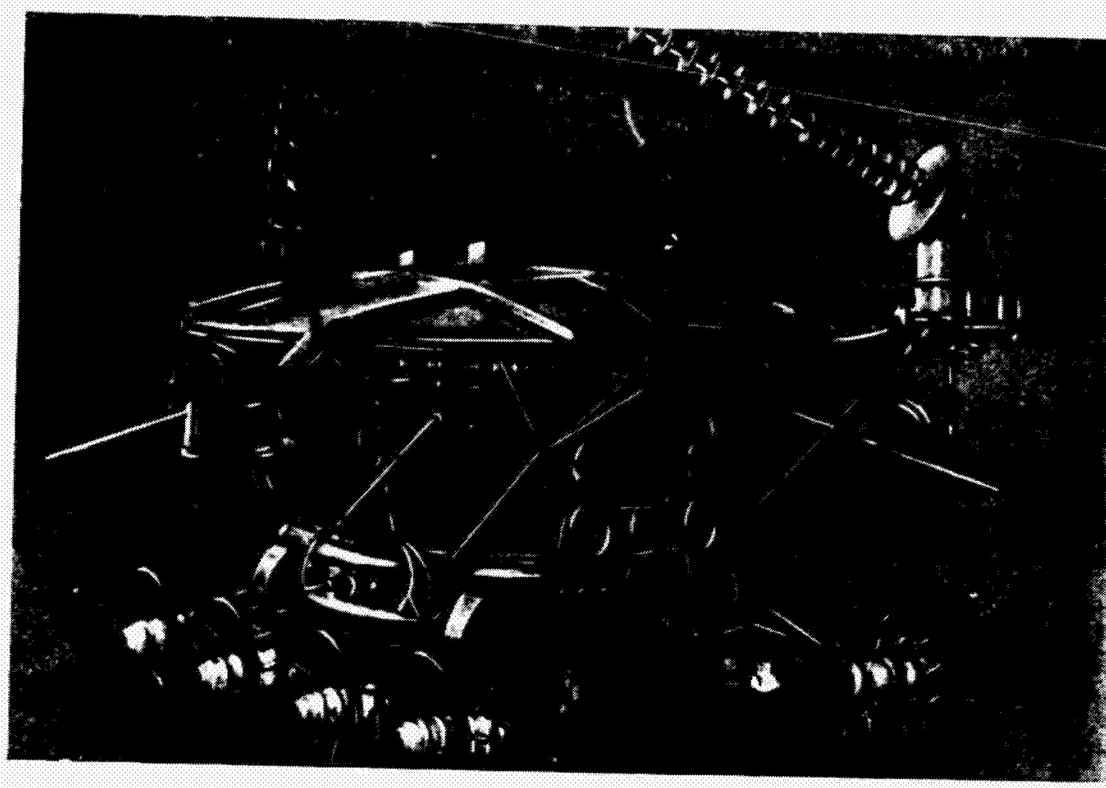
It seemed as though this machine had rolled out of the pages of a science fiction novel into the shop of the control-testing station. Two eyes of television lenses, mounted on the front of the body, four whip antennas pointing in all directions, one conical and one narrow-beam antenna for the onboard radio equipment, the sparkling lid of the "Lunokhod", supporting the solar battery, tilted backward — all of these gave this apparatus an unusual appearance.

To our terrestrial eyes, this apparatus does not correspond to esthetic concepts, which we have developed under the influence of writers and artists who have portrayed fantastic scenes. But it was built on a basis of functional principles, and these principles are different on the Earth and on the Moon.

Indeed, who really knows whether a "Lunokhod" or some other spacecraft is "beautiful". Even the word "Lunokhod" itself is a newly coined word, and we are the witnesses of the birth not only of new space words used in the profession but of cosmic esthetics as well.

This apparatus was intended for working under lunar conditions, not under terrestrial ones, so that its appearance is unusual and it has an unusual name — "Lunokhod-1".

A short time will pass and this word will be known all over the world, in all languages and dialects, in the same way that the Russian word "Sputnik" was created and remains forever.



Automatic Self-Propelled "Lunokhod-1" Vehicle. /47

Pentagonal Insignia with V. I. Lenin's Profile, Placed on Landing Platform of "Luna-17" Station.

Now, tangled in a spider's web of wires and cables, connecting it to the test panels and spans, it is in the hands of its testers, who will check the same unit ten times over with extreme care, "replaying" every operation until exact correspondence of the parameters recorded in the flight program with the data obtained during the test is achieved.

About two months still remain until the "Lunokhod" is scheduled to take off; let us follow the road which this mobile apparatus took from the drawing board to the day of its birth. Let us see how it was designed and for what it is intended.

Birth of the "Lunokhod"

Ten years ago, corresponding member of the Academy of Sciences of the USSR V. Zvonkov, in a talk with journalists said: "It is time to begin thinking about the types of roads we can take to the Moon – in a little while, terrestrial means of transport will have to be pressed into this task."

A clever and daring idea, but by no means fantastic in our time.

However, no one had yet laid out a road on the Moon. /49

The engineers and designers who built the "Lunokhod" had to solve a problem with many unknowns.

What should the self-propelled automatic device be like? How to teach it to move around on the Moon in the required directions on command from Earth and how to carry out the program of scientific research? First of all the designers had to decide what the chassis would be like?

On the Earth, we are accustomed to the fact that machines that have the greatest traction are those equipped with tracks. Calculations and experiments under lunar conditions revealed the undesirability of such an approach. In particular, it requires a great deal of energy to move tracks; they are heavy if they are strong and they are not strong if they are light. All that is necessary is to break one link in the track and the vehicle will be brought to a halt. This may be easy to fix on Earth, but what about on the Moon? In addition, during the road tests a light track would slide when it encountered a foreign object, such as a rock, and the apparatus lost its mobility. But this is by no means all. A tread system has a great many "friction pairs" which are not protected against the effects of the vacuum of space and lunar soil penetrates them, so that even if special materials have been chosen there is a marked increase in friction and consequently the required power. If we take into account the fact that in this type of drive there will be a constant exposure to the action of considerable stresses of alternating sign on the housing of the instrument container with this type of transport, it becomes clear why the tracked versions were discarded.

The designers had to go back to the wheel which has been known to man as a transportation device since the 4th millenium B.C. But what should it be like? In days gone by, in poorly developed countries where there are no good roads, arabas and two-wheeled carts with enormous wheels two or more meters in diameter are used which provide completely satisfactory motion. But could such wheels be used on the "Lunokhod"? Their large size would make them cumbersome and heavy and weight is one of the most important parameters as far as a spacecraft is concerned. Indeed, the force that would be necessary to set such wheels in motion would be great.

So, could the wheels be made smaller? Four were tried and it immediately became clear that if one of the wheels failed the "Lunokhod" would lose its ability to move.

What to do?

If the wheels were made smaller, and there were not four but eight of them, and each had independent suspension... Calculations were made, an experimental model was built and subjected to a wide range of tests. The eight-wheeled chassis proved its merit!

But what should the wheels themselves be like?

Their designers recalled a light bicycle wheel without tires. On one hub they mounted two rims with spokes and stretched a metal screen between them. The result was a light and strong wheel. But the force of gravity on the Moon is /50
six times less than that on Earth, so that the adhesion of the wheel to the ground is less. Would not such a wheel spin? Tests were conducted under conditions simulating lunar weight. They slipped. Special spikes, ground grippers, were mounted on the wheels. The wheels became similar to those that we see on the "Lunokhod-1".

Now the question arose of what the motor should be like. There was not much dispute about the fact that it must be electrical. During the lunar day, which lasts 14 of our days, the light energy from the Sun, converted by solar batteries into electrical energy, enables the "Lunokhod" to move about and permits all of its systems to operate. The choice of an electric motor was no surprise because there is no atmosphere or moisture on the Moon and this means that there are neither clouds nor fogs which would hide the Sun from us on Earth for long periods of time.

But how many motors should there be?

If one motor were used, it would be necessary to have a very complex and heavy distributing device for driving all eight wheels. Then the idea was conceived of mounting a small motor inside the hub of each wheel and equipping each motor with its own gears which would transmit the movement from the wheel motor. Thus a simple wheel became a motor wheel.

As the experiments showed, this design was completely reliable. Even when four motors were out of commission (two on one side and two on the other, or three on one side and one on the other), the "Lunokhod" did not lose its ability to move about.

In order to develop improved shock absorbing qualities, smoothness of movement of the "Lunokhod", and to ensure an easier task of overcoming small obstacles (rocks and craterlets), the wheels were joined in pairs on each side by a special independent torsion suspension. In this way, four tandem pairs were created.

One really has to see how easily and smoothly the "Lunokhod" overcomes obstacles, rolling easily over them. But how much work went into making this task so easy...

Many disputes and difficulties arose during the process of selecting the type of soil on which the "Lunokhod" tests should be held.

Should it be sand, or dust-like material, or sintered volcanic tusa? How many stones and other inclusions should there be in it?

Studies that were performed on the Moon by the Soviet "Luna-9" and "Luna-13" stations and the American "Surveyor" apparatus enabled the designers to choose terrestrial analogs of the lunar soil. However, the lunar soil which was brought back to Earth by the American astronauts on the flights of the Apollo manned spacecrafts and by the "Luna-16" automatic station of the Soviet Union confirmed the correctness of the solutions adopted in selecting the soil for the lunodrome.

Expeditions to the Caucasus, to a region that had long been dead, and to Kamchatka, in an area where active volcanoes can be found, made it possible to create a lunodrome with the necessary covering which contained all of the following: craters and stones resembling those on the Moon, individual and scattered groups of elevations, domes, scarps and contrascarps, and of course /52 fissures. Thus, the chassis and the lunodrome were ready. But did the chassis have to be checked out, and how?

The word "check out" as applied to a self-propelled device is a very broad expression; it implies movement in the necessary direction, at a given speed and with the ability to change both direction and speed at the will of the controller.

Modern automobiles are equipped with a steering wheel, gear box and a complex system for supplying the fuel mixture to the engine for these purposes. By means of the latter, the number of revolutions for the engine is regulated and at the same time the speed of the automobile is controlled by the gear box.

It is easy to see that this system of control is quite complex, cumbersome, heavy and could not be used for our purposes.

The solution to this complex problem was found gradually by the designers. What should the steering wheel be replaced by? Here they remembered one of the properties of the track version that had been discarded. Should the turns be executed by driving the wheels at different speeds on the right and left sides of the "Lunokhod" (as on a track vehicle), or should the wheels be driven in opposite directions? Electric motors make it possible to do this easily, and this would make it possible to turn on a dime! Tests were made, many of them. and the desirability of this solution was demonstrated. With the adoption of this solution to the problem, the need for a steering system of a complex nature disappeared and its function was taken over by the electronic automatic chassis block (ACB).

This mechanism took over the second responsibility – the regulation of the speed of the self-propelled chassis. In fact, to regulate the number of revolutions of the electric motor and consequently the speed of the vehicle, there is no need for either a gear box or a fuel supply system. If we take into account the fact that in rectilinear motion it is necessary to ensure that all eight wheels turn at the same speed (since each wheel on the "Lunokhod" is a motor wheel), it becomes clear that without an electronic device there can be no such thing as an automatic chassis. In addition, in the course of working out the type of control system that was ultimately chosen, consideration was given to the fact that the chassis will be a long way away from the controller (approximately 400,000 km), and it will be necessary to provide the following:

- carefully measured turns and movements of the chassis, i.e., turns through a given angle or movement at a given distance;

- immediate halting of the chassis without command from Earth in the event that conditions arise which threaten the safety of the chassis (impossibly steep slopes and differences in height, obstacles that cannot be overcome, inadmissible values for the moments on the wheels);

- the possibility of disconnecting any wheel from its drive in the event that the latter becomes stuck (thus making it possible to retain mobility and maneverability of the chassis).

This and a number of other operations were solved successfully by the automatic chassis block with the participation of special sensor apparatus and the onboard radio system. /53

In any case, however, how would this machine (the "Lunokhod") be controlled over hundreds of thousands of kilometers? What would be needed for this? How fast could the "Lunokhod" move about on the Moon? What conditions would lunar gravitation impose on movement since it is six times less than that on Earth?

This is by no means a complete list of the questions which had to be solved from scratch by the designers of the "Lunokhod".

Everybody knows that in order for an automobile to start to move it is necessary first of all to see where one is going, then to set the automobile in motion by using the controls.

But how can one drive the "Lunokhod" 400,000 km from Earth?

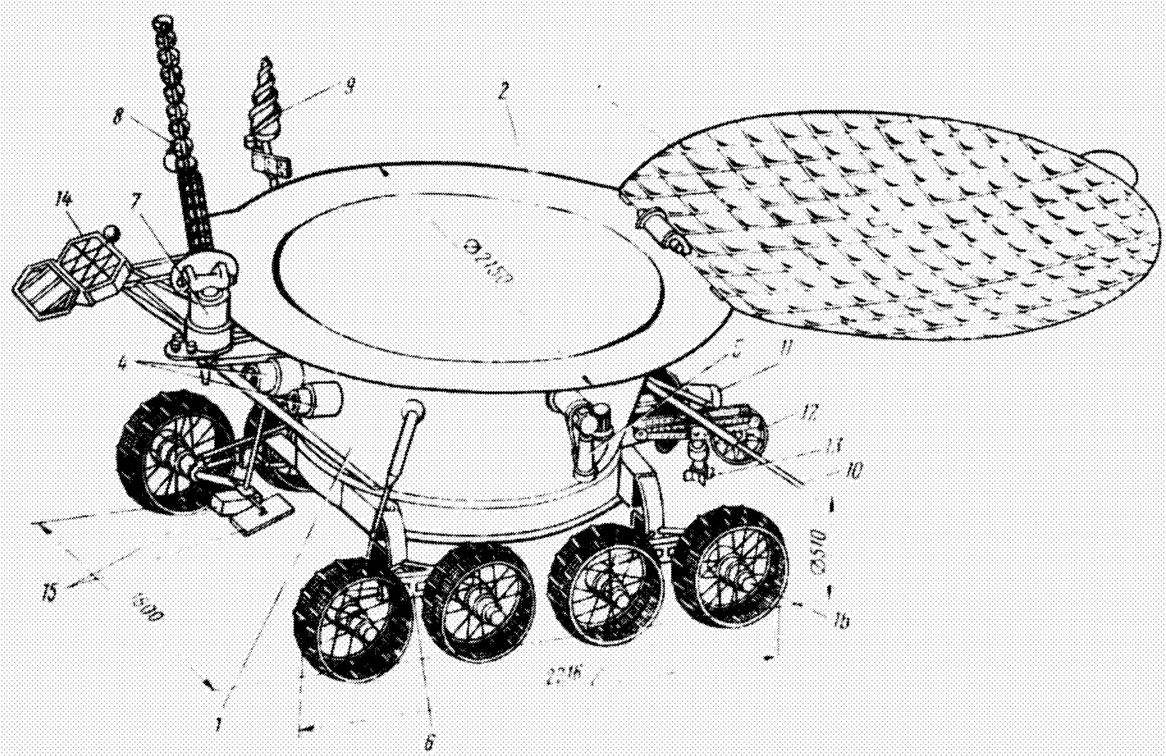


Diagram of the "Lunokhod-1" Self-Propelled Apparatus. /51
1, Body of the "Lunokhod" — hermetically sealed instrument section; 2, upper surface of the instrument compartment — radiator-cooler; 3, lid and solar battery panel; 4, television cameras; 5, telephotometers; 6, pair of wheels with torsion suspension; 7, drive mechanism for narrow-beam antenna; 8, narrow-beam antenna; 9, conical spherical broad beam antenna; 10, rod antenna; 11, isotopic source of thermal energy; 12, ninth wheel to measure distance traveled; 13, instrument for determining the permeability for ascertaining the physical and mechanical properties of the soil; 14, laser corner reflector; 15, remote unit of radio pulse measuring apparatus; 16, motor wheel.

In order to get an idea of cosmic distances, let us select two of the operations listed above as they apply to the Moon.

Thus, the "Lunokhod" is on the Moon in accordance with our wishes and we are on the Earth. We must be sure that the "Lunokhod" is ready to start moving.

in the language of the automobile driver this means: "Is there gas? Oil? Is the radiator full of water? Is the battery charged? Are the tires inflated? Is the steering gear and brake system in order? Are the headlights, parking lights and turn signals working? Is the car clean? Radio communications help in checking out the conditions of the "Lunokhod".

The radio commands, transmitted from Earth by powerful antennas at the ground control-measurement complex, will be picked up by the onboard radio system of the "Lunokhod", converted in the logic unit, and transmitted to a group of telemetric sensors which will give a radio response to radio interrogation — "the current in the solar batteries and storage batteries is normal; the temperature in the instrument compartment is +18°C, the pressure is 755 mm mercury, the inclination to the right is +2°, the trim is 1°, all of the wheels are intact, the motors are in good condition, the narrow beam antenna is aimed at the Earth, all of the systems of the "Lunokhod" are operating normally."

Let us try to estimate how much time it took to obtain this information.

The operative control group gave the command "zero", the operator carried it out (by selecting the proper code) in 0.5 second, the radio command passed from the channel through the ground converters and amplifiers along wave guides to the transmitting antenna in 0.1 second, and it took 1.3 seconds to travel from the Earth to the Moon; the onboard radio system picked up the command, deciphered it and transmitted it to the control system which carried out an interrogation of the sensors. Information which was obtained was encoded and transmitted into the ether in 0.2 second, the information made the return trip to Earth in 1.3 seconds. It was picked up and decoded in 0.1 second. Evaluation of the information obtained required 1 to 2 seconds. In accordance with the minimum estimate, 4.5 to 5.5 seconds were required.

Now that we know that the "Lunokhod" is ready, we must be able to see the way ahead and determine the directions of movement. /54

The television cameras mounted on the "Lunokhod" will enable us to see the lunar surface ahead of the "Lunokhod", but we must remember that the image which we see at a given moment in time is already 2 to 2 and 1/2 seconds old. Just try to walk down a familiar street, closing your eyes regularly for 4 to 5 seconds, and you will see what a difficult task this is. But these are the conditions under which we must control the "Lunokhod."

In addition, it is very difficult to estimate the size of obstacles and distances on the Moon. In fact, on Earth we automatically measure the distance and size of objects that we see by comparing them with objects which we know. But since this method is not perfect, it is easy to convince one's self of anything. In the movies you very often do not see and do not perceive the trick photography which is used when waves lash a ship in a movie and a whirlpool swallows it, or when a railroad train overturns or when an airplane explodes in the air. In reality, it is small scale models that sink, turn over and explode, but since there is nothing with which we can compare them, there are no familiar objects for orientation on the real scale, we do not notice it.

The crew of the "Lunokhod" finds itself under the same conditions, watching the lunar surface on the screen of the control panel. It should also be mentioned in this connection that the image on the screen is flat, and not three-dimensional; consequently, it is very difficult to determine how big the rock is which is lying on the path, how big the craters or cracks are, and how far away the wall of the crater is located. These and many other problems are constantly imposing a considerable stress not only on the driver but on the entire crew. Delicate sensors which measure the pulse, respiration, temperature, blood pressure and nervous activity of the "terrestrial cosmonauts" (this is what the first cosmonaut, Yu. A. Gagarin called the specialists on the ground who controlled the flights of spacecraft and devices, and we can include among this honored group the individuals working in this new specialty, created by the age of cosmonautics — the drivers of the "Lunokhod") clearly show what a difficult task it is to drive the "Lunokhod".

The pulse and respiration speed up, the pressure rises, the output of prespiration grows stronger as if the individual were carrying a heavy load, and the nerve stress sharply increases. After 20 to 30 minutes of driving, during which the operator makes slight movements with a small lever, he feels fatigue equivalent to that which would result from driving an automobile for 6 to 7 hours.

It is by no means an easy task to select persons who are capable of mastering the profession of driver, navigator, operator, and engineer. Tests were made with test pilots, chauffeurs with considerable experience, etc., and it was found that they could not handle this work. Their professions had already caused them to develop their own firmly established reflexes which were not suitable for operating the "Lunokhod". On the basis of newly developed tests, /55
the doctors selected a group of individuals and worked together with the engineers to teach them the new profession of "Lunokhod" driver, which was not known previously on Earth. The painstaking instruction and training for the task of driving the vehicle were initially carried out on a trainer and then with a "Lunokhod" at the lunadrome. The crews were trained to drive the "Lunokhod" for many days. It should be pointed out in this connection that the skills acquired disappeared in a short time if training was not continued.

"Lunokhod" and man can do a great deal. The "Lunokhod", subject to the will of man, can move about in any direction we desire and it sees the road ahead. And what of the man? Little by little, with great difficulty, he becomes accustomed to the lunar dimensions, to the nearby lunar horizon, to the black sky, to the sharp contrast in illumination, the blinding sun and to driving under these unusual conditions. But, having begun to move, we always have the goal of reaching a certain spot or a populated area. On Earth, roads and signs serve this purpose; but up there, where there are none, we need a compass, speedometer and map.

Unfortunately, thus far there are no large scale maps of the Moon and a terrestrial compass could not work on the Moon, since as we know it has no magnetic field.

But there is a starry sky (true, it looks different than from Earth), which we can use to orient ourselves. One can use a gyroscopic device which makes it possible to determine the direction of movement (course) by means of a special speedometer we can measure the distance traveled, and a very simple spirit level enables us to determine the list and trim of the "Lunokhod." If all of these data are transmitted to Earth, the driver can calculate the distance covered and determine the direction of travel.

Thus the navigation system aboard the "Lunokhod" was as follows: onboard telephotometers, which could transmit images of the Sun and Earth.

The radio system transmits the information to the control center. Computers analyze the pictures, determine the angle of the observation point and the azimuth of these luminaries and knowing the angle calculate the selenographic coordinates of the "Lunokhod." Gyroscopic devices make it possible to determine the size of the angles of rotation of the "Lunokhod" to the left or right of the course and maintain the direction of movement. An inclinometer-spirit level (it also measures the trim) — the portion of the specific surface with the annular grade grid superimposed on it. The role of the air bubble in inclinometer is taken here by a metal sphere. The convex portion of the sphere is directed downward and the sphere, pivoting on this point, assumes the position of minimum energy level, i.e., it always shows the position of the vertical axis of the "Lunokhod" relative to the local lunar vertical. It is a simple device, isn't it, but how necessary it is. The speedometer is the ninth passive wheel of the "Lunokhod", mounted on a parallelogram. The parallelogram has a mechanical drive so that the ninth wheel can be raised or lowered in accordance with the drivers wishes. The wheel has a counter to measure its revolutions, so that if we know the number of revolutions and the diameter of the wheel we can easily determine the distance traveled. Well suppose the speedometer wheel /56
breaks down, what then? The designers provided for this possibility too. Each of the eight wheels of the "Lunokhod" has its own revolution counter, and they can also be used to determine the distance traveled. It is true that the accuracy will be less because the front wheels may skid and turn in different directions during a maneuver such as a turn.

The question of how fast the "Lunokhod" can move is certainly a pertinent one.

Imagine that a device has been built capable of moving at the rate of 0 km an hour over the surface of the Moon. This means that it will cover almost 1/ m a second. Imagine what will happen. Remember that between the time the picture was taken that can be seen on the control panel of the "Lunokhod" and the time that the command is carried out there is an elapsed time of 2 to 2-1/2 seconds, so that the picture is 2 to 2-1/2 seconds old; consequently, the path traveled by the "Lunokhod" in 4 to 5 seconds without being subject to control is 68 to 85 m. Would you try to drive an automobile at such a speed under such conditions even on a flat highway for 4 to 5 seconds? Clearly this is impossible!

Since the force of gravity on the Moon is 6 times less than on Earth, the "Lunokhod" weighs 6 times less there.

And what about the force of adhesion and its stability? Of course these parameters are directly proportional to the weight. The greater the weight, the greater the adhesion and stability (with all other conditions being equal). And what about the perturbation, the upsetting moment?

The dynamic stability of the "Lunokhod" has become many times worse merely because it has been carried to the Moon.

Now there is one more interesting moment which must be kept in mind. Imagine that you have become an automobile tourist and that unknown and extremely interesting places are unfolding before you. You would hardly continue driving at great speed. In fact, in the most interesting places you will stop to look around and take pictures.

The same thing happens with the "Lunokhod". But this does not mean that our machine cannot cover great distances. In endurance tests on Earth, when the weight of the "Lunokhod" was adjusted to lunar conditions, the self-propelled device traveled over "lunar" roads for several hundred kilometers.

But the "Lunokhod" was not sent to the Moon simply to drive around (although of course this is very interesting in itself and has great scientific and engineering significance.)

There were more important tasks to do in conjunction with studying the Moon. One of these was to examine in the immediate vicinity as many fragments of lunar surface as possible in different regions. Then the images of the lunar relief would enable scientists and selenologists to understand the processes taking place on the Moon many millions of years ago and possibly would enable us to understand better how the Earth and solar system as a whole came to be.
How can this problem of viewing the Moon be solved aboard the "Lunokhod"? At /57
the present time, cosmovision has become a new branch of instrumentation.

Let us remember the television pictures of the Moon, especially those of the side that is not visible from Earth, which were first transmitted to Earth by the "Luna-3" and "Zond-3" stations, or the television pictures sent by the American "Mariner-4" station that managed to get a glimpse of the surface of Mars from close up.

Television from space has made it possible for man to have a look at the lunar landscape and at individual details of the lunar relief from an arm's length distance. Studying the panoramas, scientists have obtained the first data concerning the microstructure of the lunar surface, its characteristics, etc., and have obtained a general idea of the nature of the lunar relief. Cosmovision has confirmed the considerable scientific value of the method of panorama pictures using television cameras.

The television facilities of the "Luna-13" station followed the function of the densitometer mounted on the extended rod of the station, and carried out observations of the Sun, the principal navigational landmark on the Moon.

As we know, the panoramic television cameras of the "Luna-9" and "Luna-13" stations made it possible to obtain high quality transmissions with a low mass (1.3 kg) and low electrical energy consumption (2.5 watts), which is typical of the most refined types of space instrumentation.

These television devices operated reliably under considerable stress (during liftoff and when landing) in the vacuum of space and over a wide range of temperatures. In addition to the low mass and small energy consumption, the most valuable feature of these devices is their accuracy and stability of operation.

The optical-mechanical system of these stations makes it possible to transmit 500 elements of 6,000 lines each. The image which is obtained exhibits measurable properties. This means that the panoramas can be used with a high degree of accuracy to determine the size of individual details, their brightness characteristics, and to draw up a chart of the locale.

The panoramic television cameras we used aboard the "Luna-16" and "Luna-17" stations as well. The cameras mounted on the "Luna-16" station made it possible to determine under conditions of "lunar twilight" that the place where soil would be collected was bedrock.

There were four such cameras on the "Lunokhod", two on each side. One camera could "look" along the azimuth through 180° (onboard panorama along the horizon), while another could go through 360° at the angle of the observer (from the front wheel, forward to the horizon, lunar inclination of the sky, the horizon behind the "Lunokhod", the rear wheel, and completing the cycle at the front wheel). Each camera can operate either pointing forward or backward.

The principal purpose of the cameras is to scan the terrain topographically, carry out navigation measurements and study the lunar relief.

In order for the "Lunokhod" to be able to stop moving, the panoramic images are insufficient and the television devices must enable the driver to see the terrain ahead of this self-propelled machine. Here the radio engineers were required to solve a number of complicated and contradictory problems. It was /58 necessary to ensure a sufficiently large scanning angle and a good image quality with sufficiently high rate of transmission. The capacity of the communication lines (in terms of power) were limited in this respect, and the "Lunokhod" was very far away.

Naturally in this case a narrow beam antenna would have to be used to transmit the images. But how could one be sure that this antenna would be pointed out the Earth if it was mounted on a moving "Lunokhod" constantly changing its position?

This was accomplished by a system for controlling the narrow beam antenna, consisting of a ground command and onboard executing section. The operator's panel at the center had the following on it: field level indicator, a system for showing the angles of rotation of the antenna and a television monitoring device.

In the event of misalignment (the antenna not pointed toward the Earth), the level of the useful signal on the control panel of the operator decreased, and the operator would give the necessary radio commands to the system for controlling the antenna of the "Lunokhod". The drive would execute these commands, turning the antenna in the necessary direction and the quality of the television signal would be restored.

Two television cameras were mounted on the front of the "Lunokhod" housing. In this system, in contrast to the panoramic telephotometers, use was made of the classical principle of electronic television and the theoretically new methods of techniques of television transmission and signal conversion.

In the case of the "Lunokhod", taking into account the considerable distance, the low signal power and the instability of the antenna position during movement, a number of comparatively low rates for image transmission were selected at which the "time" of each frame would be measured in seconds. A higher rate of transmission would not be needed if we take into account the fact that the delay is 4.5 to 5 seconds.

While we were talking about the construction of the "Lunokhod", and about its "visual" and command sections, we touched on the radio system. Now let us get even further acquainted with it.

It is clear from what has been stated above that the onboard radio system contains the following:

The radio telemetric system which serves to interrogate the sensors, collect the information obtained in its memory and transmit the information to Earth during the communication session;

- the radio television and telephotometric system necessary for controlling the "Lunokhod" and containing the lunar panoramas;

- the command radio link along which commands are sent in the form of a code to the "Lunokhod" to switch on and shut off various systems, to carry out certain programs and finally those commands which achieve motion.

The radio system includes two units with duplicate receiving instruments, working on two wave lengths, and one set of duplicate transmitting equipment.

The command radio link and the telemetric system are also used when the station is traveling between the Earth and the Moon, during the flight of the station in orbit as a satellite of the Moon and during the landing. The landing on the Moon makes use of autonomous landing systems located on the landing platform and including a radio altimeter for considerable heights, a Doppler apparatus and a low-altitude altimeter. The first part of the book contained a description of the composition and operation of this apparatus. /59

In order to carry out its research, the "Lunokhod" is equipped with a number of scientific instruments. These include radiometric apparatus, an x-ray telescope, devices for determining the chemical composition and for investigating the mechanical properties of lunar soil, a laser corner reflector, and temperature sensors.

These devices (together with the optical-television and navigational systems of the "Lunokhod", the telemetric apparatus on the self-propelled chassis determining the force of adhesion of the wheels against the ground, the turning moment, skidding of the wheels and a number of other chassis parameters) have converted the "Lunokhod" into the first mobile automatic scientific laboratory on the Moon!

Why did the scientists choose precisely this set of scientific instruments to install on the "Lunokhod"? What tasks are these devices supposed to carry out? How are they built and how do they work? The next chapter will tell about this.

A Little Science, Scientific Instruments and Why This is Necessary

The Sun — space — the Galaxy — the Universe!

The astronomers were the first to probe their secrets. For a long time, however, it has been felt that the efforts of these scientists and their discoveries were of no significance for our earthly affairs.

With the development of a new trend in astronomy (radio astronomy) approximately 16 years ago, and especially with the development of rocket and space technology (approximately 20 years ago), when transatmospheric astronomy began its rapid development, it was found that the activity of the Sun, cosmic and x-rays, coming from the Sun and the depths of the Universe, exert an enormous influence on the processes and on life on Earth.

It was found that the weather, storms, spontaneous distress signals, and radio communications were closely linked to the activity of the Sun and the area of space surrounding the Earth. The total amount of radiant energy which the Earth receives from the Sun is characterized by a parameter which is called the solar constant. However, its magnitude and the limits within which /60
it can vary are still not clear. In addition, calculations have shown that a change in the solar constant by 1% will lead to a change in the average atmospheric temperature of approximately 1°.

How large a value this is is clear from the following example. The warming which was recorded on Earth at the beginning of the current century (especially noticeable at high latitudes) was caused by a change in the average temperature of the atmosphere by a total of 0.6°C, and the cooling that began in the 1950s was associated with a change in the average temperature of no more than 0.3°C.

Recent high altitude experiments indicate the possibility of a change in the solar constant by 2-2.5%. But it is still not known what the nature of this phenomenon is. Processes taking place on the Sun and in interplanetary space are very complicated and require an enormous number of measurements to be carried out, careful analysis of the latter, and a determination of the laws and relationships between these complex phenomenon.

What are these cosmic and x-rays? What is solar activity? What kind of a relationship do they have with one another? How can we study them? In the terminology, the word "cosmic rays" appeared about 50 years ago and was associated with an unknown and puzzling phenomenon which physicists could not explain at that time — the ionization of gases in devices. This phenomena disturbed the performance of a number of very important experiments. In determining the origin of the source of this phenomenon it was established that it had an extraterrestrial nature.

Long experiments, especially those using rocket and space technology, have enabled scientists to determine that:

- cosmic rays are fluxes of charged particles moving through the universe. They consist primarily of protons, electrons, alpha particles and the nuclei of heavy elements.

- The area of space near the Earth is filled with a great many particles with different energies, protons and electrons, which form tne radiation belt of the Earth;

- chromospheric flares on the Sun (observed in the telescope in the form of bright areas on the solar disc) emit into interplanetary space fluxes of hot plasma and cosmic rays, and fluxes of charged cosmic particles appear in a short time in the vicinity of the Earth. At these times, aurorae appear on Earth and radio communications are frequently interrupted;

- another source of cosmic rays besides the Sun consists of many stars, especially those which are in an unstable phase of development, for example, the so-called supernovae;

- the Earth's atmosphere, the magnetic field of the Earth and finally the radiation belt, on the one hand, constitute reliable screens which protect our planet and all living matter against the harmful effects of space and on the other hand do not allow many cosmophysical studies to be performed on Earth.

At the same time as these discoveries, it was established that interplanetary space has a complicated structure and is filled with magnetic fields and fluxes of solar plasma, which so to speak make up the rarefied atmosphere of the Sun, extending outward as far as the orbit of Mars, and it is even possible that cosmic rays of galactic origin, solar cosmic rays, plasma, magnetic interplanetary fields and the Earth's magnetic field are all linked by a very complicated interrelationship and interaction. /61

If the Sun is quiet (and it is very rarely quiet), the solar atmosphere will be quiet as well. Then the lines of force of the interplanetary magnetic field will have the shape of helices along which the cosmic rays move (particles with comparatively high energies), including those of galactic origin.

Cosmic galactic radiation, arising as the result of gigantic explosions on stars, are scattered into space and undergo additional acceleration to enormous energies under the influence of interstellar paramagnetic fields (on the order of billions of electron volts). Changing their direction many times under the influence of these fields, some fluxes reach our Solar System. They arrive in almost equal amounts from all directions. Thus, the Sun is quiet, its atmosphere is quiet, and the interplanetary magnetic field is quiet. But systematic observations of the Sun over the last two hundred years have indicated to scientists that a number of complicated phenomena are taking place on the Sun, referred to as solar activity.

The magnitude of solar activity is measured by the number of spots (colder areas) on the Sun's disc. The larger the spots the greater the activity and vice versa.

Observing how the number of spots on the Sun changes, i.e., how its activity changes, scientists have found that activity is subject to periodic changes appearing approximately every 11 years. This is the cycle of solar activity.

At the beginning of the cycle the number of spots is minimal, then their number increases and finally reaches a maximum, after which it starts to die down again. The more spots there are on the Sun, the greater the number of flares on the Sun, and the more powerful these flares are. As we already know, fluxes of hot plasma and solar cosmic rays are shot out into space and, moving at supersonic velocity, are captured by the helical interplanetary magnetic field, forming the so-called shock waves (an area of dense plasma with increased strength of the magnetic field). Propagating through space at the rate of several thousands of kilometers per second, the wave disturbs the stationary helical magnetic field and prevents the penetration of galactic cosmic radiation into the solar system. Consequently, when there is an increase in the number /62
of spots (more exactly, the number of flares on the Sun) the intensity of galactic cosmic radiation dies down and vice versa, when the number of spots decreases it increases. These changes are called the 11 year pattern of intensity of cosmic radiation.

Cosmic rays (the galactic variety), coming from the depths of the Universe, carry certain information about phenomena taking place out there. On their way to the solar system (the Earth) they transilluminate space. Consequently, the cosmophysicist, who studies these rays, is so to speak carrying out experiments far from Earth — at great distances from it, since it is impossible to obtain such high energy particles under terrestrial laboratory conditions, regardless of all of the achievements of modern science and technology. For these rays, the solar plasma and solar cosmic rays created in the chromospheric flares constitute a barrier which closes the way to the solar system.

In studying the interaction between the cosmic rays and the magnetic field we can study the structure of interplanetary space which in turn enables scientists to learn and perhaps to change their concepts about the nature of the Universe.

To understand the phenomena taking place on the Sun and in its depths, to learn how to predict their effects — this makes it possible to ensure the safety of cosmonauts in flight, to forecast the disruption of cosmic and terrestrial radio communications, to predict the weather more accurately, to know in advance what areas of the Earth will be subject to sudden storms, etc.

This is why the radiometric apparatus was among the first instruments which the scientists placed aboard the "Lunokhod". On the Moon there is no atmosphere and no magnetic field, so that all cosmic rays can be picked up freely.

The radiometric apparatus mounted aboard the "Lunokhod" consists of two units. One unit, consisting of gas-discharge counters and semiconducter detectors of charged particles are mounted outside the hermetically sealed housing of the "Lunokhod" while the second unit, which also has gas-discharge counters and electronic circuits as well, which transform the information picked up from the outside detectors into a form convenient for transmission by the onboard radio telemetric system, is located inside the "Lunokhod".

When charged elementary particles passed through the detector (its sensitive element is a counter), current pulses are developed in it which are transformed by electronic circuits into standard electrical impulses which are recorded stored and tramsitted to Earth during the communication sessions via the telemetric channels.

The semiconductor detectors distinguish protons in solar cosmic radiation with energies in the range from 1 to 5 million electron volts, coming from different directions. The gas-discharge counter detects the protons with energies greater than a million electron volts and electrons with energies greater than 40,000 electron volts. Comparing the measurements of the gas--discharge counter and a semiconductor detector, we can estimate the fluxes of electrons of solar cosmic rays with energies greater than 50,000 electron volts. One of the semiconductor detectors records alpha particles of solar cosmic /63
radiation with a range of energies above 5 million electron volts.

The gas-discharge counter, mounted inside the hermetically sealed housing of the "lunokhod", measures the proton fluxes with energies greater than 30 million electron volts, from both solar and galactic cosmic radiation.

Some of the counters for protons are located at different angles relative to the axis of the "Lunokhod" making it possible to measure the intensity, spectrum, direction of arrival and to estimate the composition of the cosmic rays found on the Moon.

In addition, the radiometric apparatus mounted aboard the "Lunokhod" is capable of recording the reactivity radioactivity of the surface, i.e., to act as a detector of radioactive elements on the Moon.

From the Earth, it is possible to view the Universe only through two very narrow "windows" of the entire spectrum of waves, in the visible region and in the radiowave region between several mm and tenths of meters.

All of the rest of the range of electromagnetic radiation is absorbed by the radiation belt, the ionosphere, the magnetosphere and the atmosphere of the Earth.

Studies performed in recent years have shown that these radiations (invisible from Earth) carry considerable and important information both about individual celestial objects (stars, galaxies) and about the Universe as a whole — the conditions of its origin and evolution.

The study and the investigation of x-rays and ultraviolet rays of cosmic origin has become possible only after the development of rockets and satellites capable of rising to altitudes above 100 km above the surface of the Earth, since x-rays are absorbed by the atmosphere at altitudes less than 100 km and the ultraviolet radiation is considerably attenuated by it.

The first discrete sources of x-rays from space were detected in 1962, when experiments were performed to measure the x-radiation from the Moon which, as it was felt, could have arisen under the influence of bombardment of the lunar surface by cosmic rays. But it proved impossible to detect any x-rays from the Moon, so that one of the most important discoveries of the 20th century was made — sources of cosmic x-rays were discovered. The first experiments performed with the launching of rockets that were fired vertically (to altitudes up to 1,000 km) established that the Sun is a powerful source of short wave, x and ultraviolet radiation. Further observations yielded important information about the structure of the Sun (its external envelope) and about the physical processes that occur on it, and regarding their influence on the ionosphere, magnetosphere and atmosphere of the Earth and consequently on life on Earth.

A great deal of space was devoted in these works to the "Interkosmos" program. Studies in recent years performed by means of rockets and satellites have provided extremely interesting data. The ultraviolet radiation from the stars has been studied; the corona surrounding the Earth has been discovered, glowing in the far ultraviolet. Several dozen discrete sources of x-radiation were discovered (approximately 50), some of which (12) were associated with known optical objects, while 4 sources are located outside our Galaxy. A diffuse x-ray "background" in cosmic space was detected, i.e., it was found that the entire universe surrounding us is glowing with x-rays, but the reason for this radiation has not yet been explained. /64

Fluxes of x-rays reaching us from cosmic sources are very weak, which makes it very difficult to study them. Their intensity varies from 0.1 to 20 photons per cm^2 per second, and it is not considered possible to study weaker radiation (less than 0.1 photon) at the present time.

But we should not think that once we have detected such weak radiation on Earth that all of the sources of such radiation are the same. As calculations have shown, x-rays from a source located in the constellation Scorpio are 1,000 times more powerful than the radiation of our Sun (x-ray, thermal, light and radio emissions combined).

Thus far, however, scientists have been able to say very little about the nature of such x-ray stars. Only in the case of a few sources of x-radiation do we know the distribution of energy in their spectrum and their angular size. However, on the basis of these data scientists can construct models of sources of x-radiation (the structure and physical processes going on in them).

It has been suggested that a number of x-ray stars have temperatures of several tens of millions of degrees and measure only several tens of kilometers, i.e., their density reaches extraordinary values — 100,000,000 tons in 1 cubic centimeter!

The enormous radiant energy from these stars, called "neutron stars" is explained by the thermonuclear reactions that take place at their cores. Apparently there was an initial "combustion" — conversion of hydrogen into helium, afterwhich increasingly heavy elements began to "burn" and finally, at the end of this evolutionary process, when all of the elements had been "burned up", the "neutron star" appeared. In observing "neutron stars", scientists have been able to detect pulsations in the radiation from certain stars; hence, these stars have been called "pulsars". It is possible that the "pulsars" are "neutron stars" which have a powerful magnetic field.

A very interesting "pulsar" was discovered in the Crab Nebula; the x-radiation, radio emissions and optical radiation all pulsate at the same rate. No other x-ray sources with pulsating radiation have yet been found. /65

In view of the fact that the Crab Nebula appeared at the site of one of the supernovae, it may be assumed that some x-ray stars are the remains of "old" supernovae. In our galaxy supernovae flare up every few hundred years.

As we can see, there are more than enough unexplained questions concerning the nature of x-radiation, the processes taking place in sources of x-radiation, concerning the nature and the structure of neutron stars, pulsars, quasars (newly discovered very powerful sources of x-radiation, located at a distance of billions of light years from our galaxy and having relatively small dimensions, radiating energy tens of thousands of time stronger than the stars in our galaxy), sources of colossal energy.

If we consider that all of this is of great significance in the unlocking of the secrets of thermonuclear reactions, as well as in understanding the processes occurring in our universe and the pathways which its further development will take, it becomes understandable why the scientists have such tremendous interests in these studies. In order to answer the questions posed above as well as a great many others, it is necessary to conduct prolonged and systematic studies of various areas of space.

At the present time, the duration of the x-ray astronomical observations carried out primarily by instruments elevated above the limits of the atmosphere by means of rockets, can be measured in several hours all over the world. This is why an astronomical observatory located on the Moon is the dream of scientists. Atmosphere, ionosphere, magnetosphere and radiation belts, all of which absorb and influence radiation, are nonexistent on the Moon. It becomes possible to carry out long and continuous observations, since the Moon revolves very slowly (one revolution in 27.3 Earth days), making it possible to direct the instrument at the object under study with a considerable amount of accuracy and keep it in the field of vision for a long time, gaining information about weak sources of radiation. In addition, the lack of wind and a force of gravity which is 6 times less than that on Earth would make it possible to build instruments of tremendous size on the Moon and consequently increase their sensitivity a thousandfold, so that the position of radiation sources could be ascertained with great precision.

It is clear from the above why the second scientific instrument of the "Lunokhod-1" was a small x-ray telescope. The device consists of two individual counters of x-ray photons. One of them is the working instrument, sensitive to the spectral range from 2 to 10 Angstroms and has a field division of 3 degrees. The second counter is the control; it is not sensitive to x-radiation and makes it possible to check the background of cosmic radiation.

The lengthwise axes of both counters are directed toward the lunar zenith, and as the Moon rotates, the three-degree sector slowly slides along the celestial sphere, capturing x-radiation from distant sources. /66

Each photon reaching the counter generates an electrical impulse, which after being amplified in the electronic amplifier enters a special counter, then is passed on to a memory device whence the stored information is "counted" during the radio communications sessions and transmitted to Earth.

The x-ray telescope makes it possible to carry out measurements during the periods between communication sessions for periods of 18 hours, when it is not possible to have active communications with the "Lunokhod" since during this period of time (thanks to the daily rotation of the Earth) the "Lunokhod" is not in the field of vision of the terrestrial instruments located in the territory of the Soviet Union.

The time during which accumulation of information takes place (the length of a single exposure) is 6 hours, and there are three such exposures in one Earth day, which is almost one thousand times greater than the capacity of any rocket experiment. If we take into account that the sensitivity of the instrument is increased tenfold, it becomes clear what enormous scientific significance is attached to this experiment. Scientists expect that it will be possible to determine the density of the gas in the universe and thereby answer the question of what cosmological fate awaits it. At the present time it has been established by radio astronomy that our universe has been expanding for the last ten billion years, i.e., galaxies far away from us are receding and the further away they are, the faster they travel. How long can this process continue? What will happen then? There are two diametrically opposite answers to this question as provided by theory.

If the density of the interstellar gas is less than the critical value (approximately 1 atom of hydrogen per 100,000 cubic centimeters of space), the universe will expand forever; if it is greater, then in approximately ten to twenty billion years the expansion will cease and contraction will begin, ending by the universe being compressed into a single point.

Thus far we have been talking about instruments which will enable the scientists to understand the universe, but the "Lunokhod-1" is a self-propelled device intended for investigating the lunar surface. What kind of instruments does it carry for this purpose?

In order to perform a chemical analysis of the composition of the soil (rather, to determine the type of rocks making up the lunar surface), the "Lunokhod" has mounted aboard it an x-ray spectrometer of the "Rifma" type (x-ray isotopic fluorescent method of analysis).

The operating principal of this instrument consists in the following. By means of a radioactive isotope (contained in a special ampoule), the area of the ground which is of interest is irradiated. As a result, induced radioactivity is created in the soil and the soil itself begins to emit radiation. Each of the chemical elements contained in the soil gives off radiation with a certain wavelength (specific energy). This radiation is, so to speak, the /67
calling card of the element in question. Consequently the problem boils down to recording this radiation and collecting the calling cards.

To do this, 10 proportional counters are used, each of which is a tube containing a gas to which a certain voltage is applied. The entire tube is covered by a shield and there is a 5 micron slit at one place only, through which the x-radiation from the radioactivity induced in the soil can pass (during the period of irradiation of the soil by the radioactive isotope the counters are covered by a shield). Under the influence of this radiation, the gas in the tube is ionized and an electrical current begins to flow through the ionized gas between electrodes. The magnitude of this current is proportional to the energy of the radiation and corresponds to the element in question. Thanks to this instrument, geochemists located on Earth are able to determine the chemical composition and the type of material on the Moon at the location of the "Lunokhod", i.e., in various regions of the lunar surface.

Simultaneously with the investigation of the chemical composition of the lunar soil, the "Lunokhod" carries out a study of its mechanical properties by means of a special device called a penetrometer.

The penetrometer is a word that comes from a combination of the Latin word "penetro", "I penetrate" and the Greek μετρεω, "I measure", i.e., I measure the properties as indicated by penetration into the depth of the material. The process of simultaneous penetration into the material and the measurement of its properties is called penetration.

The penetrometer is mounted on a hinged parallelogram, so that it can move in the vertical plane. In order to move the penetrometer in the vertical plane, a special electric motor with a gear box and sensors which record the depth of penetration of the working portion of the penetrometer into the soil and the resistance to this penetration (compression) is used. The working element of the penetrometer is a cone with cruciform blades.

After the cone has penetrated to a certain depth, a second electric motor causes it to turn around its lengthwise axis. The angle of rotation of the cone and the force of resistance to this rotation (shift) are determined. During the penetration process, at a given point, we will obtain not a single value (point) indicating the properties of the soil, but an entire curve which describes the law of the change of the properties of lunar soil with depth. This ability to study the mechanical properties of the soil is a great step forward in comparison with the method of measurement which was used experimentally aboard the "Luna-13" station.

It should be kept in mind that the characteristics of the mechanical properties of the soil, as determined with the aid of the penetrometer, are extremely necessary not only to the scientist but to the designers who will build future means of transportation on the Moon.

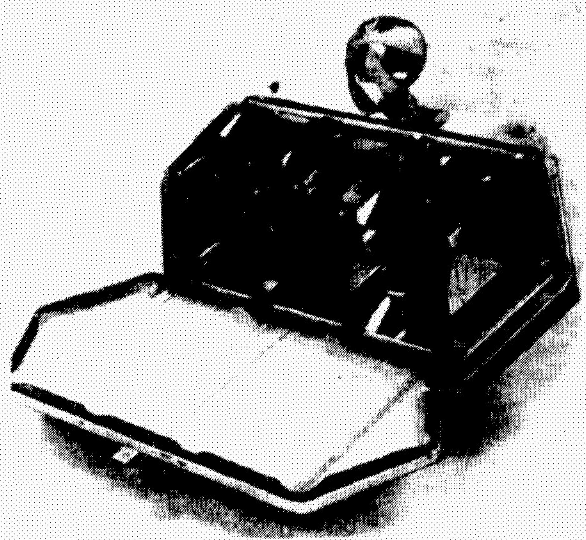
We can hope that the research which is carried out by the instruments and /68
the x-ray spectrometers of the "Rifma" type and the penetrometers in conjunction with direct studies of the lunar soil brought back to Earth by automatic stations of the "Luna-16" type will make it possible to reveal some of the secrets of the Moon's origin and will help in the solution of other cosmogonic problems.

Among the scientific instruments mounted aboard the "Lunokhod", a particular place has been reserved for the laser corner reflector. This device, in conjunction with ground receiving-transmitting facilities equipped with laser-direction finding apparatus, is intended to answer a number of questions of interest to astronomers, geologists, physicists, communication specialists and scientists in a number of other disciplines.

The inclusion of this experiment was possible because of the development and accomplishments of quantum radiophysics and due to the development of powerful pulsed lasers which possess enormous spectral density of light energy and considerable directionality of the radiation beam.

The laser reflector was built by French scientists and engineers in accordance with the Franco-Soviet agreement on cooperation in the study and conquest of space for peaceful purposes.

This is a special light reflector composed of 14 triangular prisms measuring 100 mm on the side. Each of the prisms forms a corner cut from a cube in such a fashion that 3 angles of this prism are right angles at the vertex and the base of the prism is the section plane.



In Order to Carry Out Its Scientific Research, the "Lunokhod-1" was Equipped with a Variety of Scientific Instruments, Including This French Laser Corner Reflector.

If a ray of light is passed through the section plane (in any direction), the triple internal reflection in the prism will cause the beam to emerge in a direction which is exactly opposite to the incident beam and in the same plane with it. This property of a rectangular triangular prism completely and totally depends on how /69 accurately the right angles at the vertex are made during manufacture. If the angles are made with low accuracy, the incident beam and the reflected beam will diverge and the reflected beam will be unable to return to the point whence it came. In order to obtain a reflected beam from the Moon by means of a corner reflector, the right angles between the size of the prism must be made with an accuracy of tenths of a second of angle.

By itself, the construction of such a prism constitutes a complicated engineering and physical feat. But if we add to it the fact that the prism must withstand temperature changes of more than 300° Celsius, while continuing to retain its geometric characteristics, in order that the prism can retain its optical characteristics, regardless of the influence of cosmic and x-ray radiation, it becomes understandable that it is not very easy to make such a "mirror".

In order to make the prism, special glass was used which is uniform in structure and has small coefficients of thermal expansion and small index of refraction.

Considerable attention was paid to the problem of thermal protection for the prism, which was provided by minimum thermal exchange between the prisms and the housing of the "Lunokhod" in order for the temperature of all the prisms and their individual parts to be the same.

It is natural that the "mirror" itself, the laser reflector, will not transmit any information that is interesting to scientists on Earth. In order for the "mirror" to speak, it must be "illuminated". For "illumination", as we mentioned already, the system of ground laser direction finding apparatus is used.

One portion of this apparatus was built by Soviet scientists and engineers and installed on the largest optical telescope in Europe (diameter 2.6 m) at the Crimean Astrophysical Observatory of the Academy of Sciences of the USSR.

A second unit was devised and built by French engineers and mounted on the 1.05 meter telescope located at the Pic du Midi Observatory in the Pyrenees.

These units included the following:

An optical converter using a ruby laser with modulated resolution and a pulse lens on the order of one hundred millionth of a second;

a narrow-band photoreceiver with a system for recording the reflected signal;

a device for measuring the propagation time of the light signal to the reflector and back with a measurement accuracy on the order of one hundred millionth of a second;

a unit containing automatic devices and controls for the entire apparatus.

The essence of the experiment of laser location consisted in the following. Knowing the coordinates of the location of the laser reflector ("Lunokhod") on the Moon, on the basis of known characteristic lunar formations, acting as reference points, the telescope (and consequently the ruby laser) is aimed at /70 the point in question at the lunar surface. The laser is activated, the light pulses are emitted (as a directional, strictly ordered single front) with a pulse length on the order of one hundred millionth of a second and a pulse power of several joules. The repetition frequency of these pulses is 4 per second.

Leaving the laser and passing through the optical system of the telescope, the light quanta, literally the "bullets", head for the Moon in a compact group.

At the same time that the "shot" takes place, clocks begin to operate — instruments are measuring the time required for the light signal to travel and having accuracy of the same order as the duration of the pulses. A portion of the quanta, after covering the distance from the Earth to the Moon with the speed of light, has reached its surface. However, while it had the shape of a very fine beam when it left the telescope, as a result of optical divergence of the beam after passing through the telescope, measured in several seconds, we will have on the Moon not a brightly illuminated point but a spot of light 5 km in radius. The light energy of the laser transmitted from Earth is spread out over this spot (with the exception of that energy which was scattered in the Earth's atmosphere).

Although the laser reflecter mounted on the "Lunokhod" (this is where it is needed) has a limited area on the order of 100 cm^2 (the area is very small in comparison with the area of a circle 5 km in radius), it ensures a strictly guided reflection of the beam to the Earth end thanks to its small size constitutes a strictly localized, practically point target, which does not introduce any additional errors into the measured distance due to its intrinsic dimensions.

Thus, a small portion of the light pulse transmitted from Earth has been reflected from the "mirror" – laser reflector – and has returned to Earth, exactly at the same point whence it came. After reaching the atmosphere of the Earth, a portion of the reflected light energy will again be scattered by the atmosphere and only tens or in the case of the beam hundreds of quanta (units of light energy) out of the many hundreds of thousands which began their journey through space from the telescope will return to the origin.

Passing through the optical system of the telescope, they will reach the ocular, where a receiver is mounted (photomultiplier) with a system for recording the reflected signal. In terms of its principle of operation this device can be compared with an avalanche which is caused by a small pellet of snow rolling down from the top of a mountain slope.

The role of the small pellet of snow is played by a quantum of light energy. Striking the photoelectronic screen, made of metal, which easily loses its electrons, it knocks an electron out of it which is captured by the electrical field produced between the plates, accelerated and finally striking the next plate at the end of its travel. But since its energy is much greater than that of the quantum of light, it produces not one but two or even three electrons. These electrons continue their journey, similarly to the path of the first /71
electron, from plate to plate, and finally they strike the last plate, and an avalanche of electrons floods the pulse counter. Thus, the signal is amplified hundreds of thousands of millions of times. Together with the useful signal (that which we are waiting for) their ground apparatus can pick up light noise which is also amplified and creates strong interference. It is therefore necessary to take into account that not every quantum causes the production of an electron. Therefore the performance of this delicate experiment requires considerable skill on the part of the experimenters, a powerful radiator and a highly sensitive receiving and recording instrument.

The quantum has finished its journey. The starting time and finishing time have been recorded with high accuracy. The wavelength of the laser is measured in centimeters, so that the distance to the Moon can be measured with an accuracy up to 1 cm. But the only problem is that the reflected signal is "blurred" because of its weakness and because of the noise. In addition, the accuracy of the measurements is somewhat worse (from tens of centimeters to several meters). But if we take into account that the methods of calculating the movement of the Moon which exist at the present time are based on the laws of universal gravitation of Newton and on goniometric measurements, and have an accuracy on the order of hundreds of meters, it becomes clear that the new method of laser location, even in its present form, makes it possible to carry out astrometric measurements of the basic parameters of the Earth and Moon which are ten to one hundred times more accurate.

The method of laser location makes it possible to investigate in detail the process of the rotation of the Moon around its own axis as well as its liberation, making it possible to penetrate the secrets of its internal structure.

It may be expected that the method of laser location will be used in the near future for studying the movements of cosmic objects (for example, lunar satellites), trajectory measurements, and for locating nearby planets.

Laser location will also make it possible to solve a number of important particularly terrestrial problems having to do with precise geodetic measurements, and to proceed on this basis to investigate and solve the fundamental problem, the one which is most interesting for geologists — is there such a thing as continental drift and movement of the poles of the Earth.

The experiment which was designed jointly by the scientists of the two countries was extremely interesting. It represents a great step forward in the development of new laser-location methods. The results of the joint experiment will be used in new research, and the experience gained from working together will serve as a means of strengthening the cooperation between the scientists of the USSR and France and in the final analysis will further peace on our planet.

In addition to the apparatus which we mentioned above, the "Lunokhod" is fitted with a number of temperature sensors mounted both inside the hermetically sealed housing of the "Lunokhod" and on its exposed surfaces, on the top of the /72 "Lunokhod" where the solar batteries are located, on the hubs of the wheels, on the telephotometers, on the apertures-objectives of the cameras of the small-scale television system and in many other areas.

In addition to determining the temperature conditions on the lunar surface during the lunar morning, day, evening and night, in the shadow and in the sunlight, which are of tremendous scientific interest in themselves, these measurements are very necessary to the designers of future lunokhods and their systems.

In addition, without the temperature sensors that go to make up the systems of temperature regulation and those mounted inside the hermetically sealed housing on various heat-emitting devices, it would be impossible to provide the necessary temperature conditions inside the "Lunokhod". All of the "Lunokhod" systems must pass an examination under harsh lunar conditions. On the Moon the "Lunokhod" must withstand temperatures from +130° Celsius to -160° Celsius and must not only withstand them but must be able to function under these conditions. At a temperature of -40 to -50° Celsius, steel becomes brittle and tin "contracts" tin disease.

Some Other Systems That Cannot be Done Without

The temperature conditions in the hermetically sealed compartment and on various surfaces of the "Lunokhod" structure is controlled by a combination of two methods of temperature regulation — active and passive.

Passive regulation is accomplished through thermal insulation and covering surfaces that are not protected by thermal insulation by paint with certain optical coefficients.

Active regulation is accomplished through a gas system for temperature regulation which controls the temperature in the hermetically sealed compartment within limits from 0° Celsius to 40° Celsius. The active regulation system consists of the following:

A cold circuit consisting of a radiator-cooler, which radiates heat into space, and four evaporators, heat exchangers, in which gas is cooled through the evaporation of water. The radiator is mounted on the roof of the sealed compartment and the heat exchangers are mounted on pipes which run from the radiator to the field compartment and provide additional cooling of the gas during periods that require considerable output of heat (prolonged movement when the Sun is high). The cold circuit provides normal functioning of the apparatus, as a rule, during the lunar day.

The hot circuit, which consists of an isotopic heat source with a heat exchanger. What is an isotopic heat source? How does it work? A great deal /73 of energy is contained in the atom. Man has penetrated the secrets of nuclear processes and has begun to use atomic energy. Any thermonuclear reaction is accompanied by the liberation of heat and the only question is how rapidly the heat is liberated and whether it can be used.

Naturally, the heat which is emitted as the result of a thermonuclear explosion cannot be used for peaceful purposes, but the energy from radioactive isotopes, which give off alpha and beta particles and gamma quanta as they decay can be used for obtaining thermal and electrical energy.

It is not very difficult to find some protection against the radiation in this case, because we know for example, that alpha particles from the isotopes polonium-210, plutonium-238, curium-242, etc. are helium nuclei which have a low penetrating power and can penetrate only a few microns when they strike a metal (the housing in which the isotope is contained) and are therefore completely stopped. The energy from the decay process is thus converted into heat in the mass of the isotope itself.

Taking into account that the process of decay of a radioactive isotope is going in continuously and lasts for certain periods of time, we can select a particular isotope and a specific amount of it which is necessary to obtain a certain amount of heat for a certain period of time.

Thus, for example, polonium-210 has a relatively short half-life, 138 days. During this period of time it gives off up to 40-50% of the energy stored in it during its formation in an atomic reactor. Plutonium-238 has a half-life of approximately 90 years. Naturally, such an isotope would be advisable for use in systems with very long operating cycles or for repeated use.

Aboard the "Lunokhod-1" the ampoule for the isotope and the heat exchanger in which it is located are made of a heat resistant material which makes it possible to obtain thermal energy at high temperature levels, thus allowing the unit to be small in size, hermetically sealed and strong.

During the lunar night, when the temperature on the surface of the Moon reaches -160° Celsius, and the temperature inside the sealed container of the "Lunokhod" reaches the lowest permissible level, automatic systems shut off the lines running to the cold circuit and direct the gas into the hot circuit that leads to the heat exchanger. The gas moving along the walls of the heat exchanger picks up heat and carries it into the field compartment. In this way, normal temperature conditions are produced inside the field compartment during the lunar night. During the lunar day the heat is radiated into space through the outer walls of the heat exchanger.

Systems of baffles and electrical fans enable the gas to move inside the compartment to the heat exchangers in the required direction as a function of /74
the temperature conditions inside the field compartment.

Naturally, the function of any system of the "Lunokhod" is unthinkable without the reliable and proper functioning of the electrical supply system.

This system, as we already know, consists of solar batteries mounted on the open lid of the "Lunokhod"; the chemical power sources are storage batteries which store the electrical energy from the solar batteries; there are also distributing and converting devices as well as networks of cables.

The solar battery (lid) can be opened to different angles by means of an electric motor so that the most favo[illegible]e conditions will be created for obtaining electrical energy. The position of the plane of the lid is 90° with respect to a line drawn from it to the Sun. During the lunar night, the solar panels close down tightly against the top of the hermetically sealed compartment and obtain the necessary heat from it.

As the result, the elements of the solar battery are protected by thermal insulation mounted on the outer surface of the lid; inside the field compartment, the necessary temperature conditions are maintained.

With the coming of lunar morning at the location of the "Lunokhod", the lid containing the solar batteries can be opened either automatically in response to a signal from a sun sensor or on command from Earth.

The solar battery provides the electrical power for the entire station (landing platform and "Lunokhod") during flight from Earth to the Moon and during the flight in orbit as an artificial satellite of the Moon.

Where Are the Similarities and Where Are the Differences?

In the block house, the technicians are finishing their tests and preparations for the launching of the "Luna-17".

Let us have a close look at it. It is very similar to its predecessor, the "Luna-16" station. Their landing platforms are similar, and that is no accident.

In approaching the task of designing a new generation of stations in the "Luna" series, the engineers and designers were faced with the task of building a unified landing stage, a lunar module which could be used for transporting different kinds of instruments to the Moon intended for carrying out a wide variety of research programs.

As we already know, they dealt successfully with this problem. The difference between the landing platforms of the "Luna-17" and "Luna-16" stations consists in the presence of ramps and the lack of a second instrument package and soil collecting apparatus.

Two ramps mounted on the landing stage of the "Luna-16" station each consist of three parts — a center section mounted to the landing platform in a rigid fashion (it serves as a support for the wheels of the "Lunokhod" during /75
the flight) and two tilting sections, front and rear. The tilting parts of the ramp consist of two sections hinged together. They are also hinged to the landing platform.

During the flight they are held by clamps in a folded vertical position. After the landing, on command from Earth, the ramps are freed from the clamps and unfolded by springs so that they extend down to the lunar soil.

On the external lateral surfaces of each ramp are welts which do not allow the "Lunokhod" to slip sideways as it descends from the landing platform.

The designers spent alot of trouble in working out these mechanical devices, which look so simple at first glance, especially during the adjustments and tests.

Again and again the same questions were answered: weight, strength and reliability.

But each time the solution was new and completely unexpected.

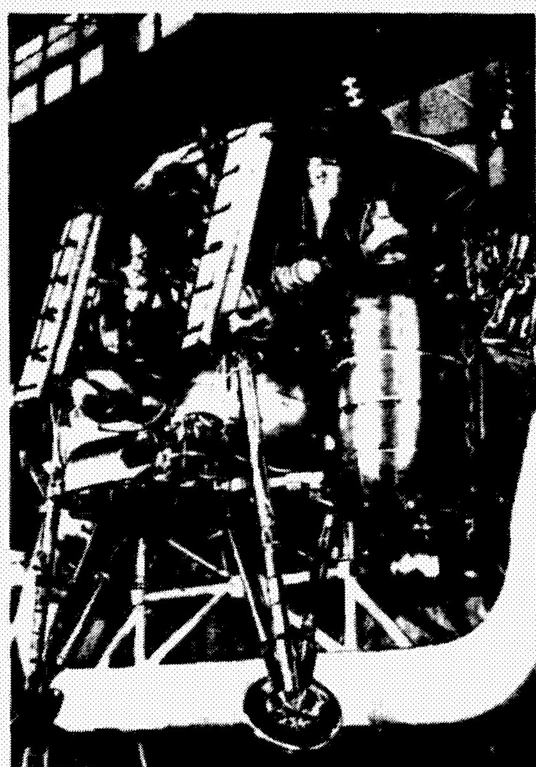
Our introduction to the "Lunokhod" is at an end.

The electrical tests of the "Lunokhod" have been completed and the landing platform is in its operating position.

The "Lunokhod" and the platform are covered by shielding and vacuum insulation which protects them against the cold of space and the incinerating rays of the Sun.

After this operation, the "Lunokhod" together with the landing platform /76
is mounted on the carrier rocket which has also been subjected to all manner of tests beforehand.

After putting the nose section on the rocket, the rocket assembly was brought to the launching site and connected to the launching mechanism. The service gantry was brought up. The prelaunch testing and electrical connection were begun. Everything is automatic and proceeds according to the strictly specified plan. Operation follows operation and finally the last tests are being carried out. The members of the state commission on the preparation and carrying out of the launch of the rocket complex with "Lunokhod" onboard have gathered in the hall.



"Luna-17" Automatic Station In the Assembly-Testing Rack.

The responsible directors report to the state commission on the readiness of the "Lunokhod" and rocket systems for launching.

The decision is made: go ahead filling the rocket with fuel and carry out the launch at the appointed time.

The most responsible and tense hours of the task have come — checkout.

All of the specialists who are not involved in this operation look at the gantry tower and the launch pad.

Powerful pumps convey many hundreds of tons of fuel at the appointed time from storage tanks into the tanks of the rockets. The devices "follow" and "report" to the block house concerning the progress of these operations.

Preparation is complete. One after the other, the last testers leave the service gantry and the gantry itself, tall as a fourteen story building, smoothly rolls away from the rocket.

It would be difficult to find anybody among those present at the launch who was calm during these minutes preceding liftoff.

These moments are filled with joy and fear simultaneously, every time.

And no matter how you try to capture the moment of the launch, although the countdown can be heard over the loudspeaker system, it is always unexpected, like the avalanche of snow in the mountains.

On the Way to the Moon Again

On 10 October 1970, at 1744 Moscow time, the Kazakh soil saw the launching of the "Luna-17" automatic station toward the Moon, carrying the automatic self-propelled device called the "Lunokhod-1".

Why was the rocket launched on 10 October and not on the 12th or the 20th?

We can only answer this question if we know the purpose of the flight, the laws of ballistics and celestial mechanics, as well as the engineering capacity of the automatic station systems.

In order to select the most favorable date for launching the "Luna-17" station, it was necessary to take two conditions into account. The first condition (or as it is called, limitation) has to do with the fact that three heavenly bodies (the Moon, the Earth, the Sun) are continually changing their positions in space. In order for the onboard astroorientation systems to work, /77
it is necessary to know exactly the specific and most favorable angular positions of the Earth and the Sun, since the orientation of the station in space is accomplished as a function of these luminaries. In addition, the orientation system has structural angular limitations.

The second limitation is imposed by the diurnal rotation of the Earth, depriving us of the possibility of following the flight of the station by means of terrestrial radio instruments located in the territory of the Soviet Union.

Consequently, it is necessary to select flight conditions such that these interruptions in communications will be minimal.

Taking these limitations into account, as well as the laws of motion and attraction of the Sun, Earth and Moon and the most favorable positions of the Sun, Earth and Moon for the launch from the standpoint of optimum energy expenditure, high speed computers were used to calculate the time intervals in all months ("windows") which were favorable for the launching and the flight to the Moon.

But this is only a portion of the problem. The final goal of our flight is a soft landing in a specified region of the Moon at a specific time.

As we already know, a landing in a specified area can be made precisely only from a certain lunar orbit, i.e., the orbit must have a certain angle of inclination to the lunar equator, a specific apolune and perilune and the return package must have a specific position in orbit. In order to create this orbit it is necessary to have correction sessions, and the correction session must be preceded by an orientation session, but the orientation, as we have already said, can only be carried out within a certain range of angles between the Earth and the Sun (the difficulty here lies in the fact that the terrestrial optical instrument of the astroorientation system cannot "untangle" the Earth from the Moon, inasmuch as the brightness of the Moon due to its proximity becomes equal to that of the Earth). To this must be added the limitation with respect to radiovisibility of the station during its time in orbit due to its radio blackout behind the Moon and the daily location of the Earth.

But this is still not all. There are limitations as far as the supply of the fuel aboard the station is concerned, necessary for braking the station as it is inserted into orbit as a lunar satellite, for carrying out corrections in establishing the orbit, for braking during descent of the station from orbit and during landing, and also limitations on the luminance and radiovisibility of the station at the landing site. In order to move it is necessary first of all to see where one is going to move to and secondly it is necessary to have energy (as provided by the solar battery) and thirdly it is necessary to have "radiovisibility" for control.

Having determined the zones of all of the limitations mentioned above, one can proceed to solve the basic problem.

Given the limiting values of the parameters on the "lunar", final portion of the trajectory, the basic characteristics are calculated (launch time, energy, etc.) for the "terrestrial" initial portion of the trajectory. But the /78
initial portion of the trajectory — the "launch window" — has already been determined and if we do not go through this "window" in solving the boundary problem the calculations must be repeated. This involves varying the parameters of the final portion of the trajectory within the permissible limits until the solution is found.

It would be impossible to carry out these tedious calculations in the short periods of time available without modern high speed means of computer technology and without individuals who are completely in command of them.

The reliability and skill of the work produced at the computer center, the operational and reliable functioning of the methods of trajectory measurement or, as they say, the ballistic guarantee, largely determine the successful solution of the space problem.

Each flight to the Moon is simultaneously a new and an old trip. It is a new trip because every time a new problem is solved using new methods and it is an old trip because this is the road from the Earth to the Moon to which man has already begun to become accustomed. But this is a tough and difficult role and there is a great deal of hard work on the part of many thousands of people behind the laconic lines found in Tass reports about the flights of the stations!

During the flight of the "Luna-17" station on its way from the Earth to the Moon, 36 radio communication sessions were held, during which the trajectory parameters indicating the movement of the station were measured and the telemetric information concerning the function of onboard systems was collected.

The trajectory measurements by means of electronic devices were conducted on the 11th and 12th of November by means of optical-phototelevision apparatus mounted on the high altitude observatory of the Astronomical Institute imeni Shternberg in Zailiyskiy Alatau (near Alma-Ata) at the Shemakhin Astrophysical

Observatory on Mount Pirkuli and at the Observatory of the Institute of Astrophysics of the Academy of Sciences of the Tadzhik SSR in Dushanbe. At this time, the station was 200 to 240,000 kilometers distant from Earth and could be seen as an object of twelfth stellar magnitude.

In order to ensure that the station would enter the specified region of space near the Moon, on the 12th and 14th of November two correction sessions to adjust the trajectory were held.

During the approach to the Moon, a braking session was held to shift the station into orbit around the Moon.

The correction and braking sessions were preceded by astroorientation sessions during which the station dutifully sought out luminaries, the Sun and the Earth, carried out programmed turns relative to the reference systems of coordinates, remained in this position as the correcting-braking motor assembly operated, and returned to its original flight attitude.

During the flight from the Earth to the Moon the onboard automatic devices also controlled the opening and closing of the solar battery panels of the "Lunokhod-1" and its orientation with respect to the Sun in order to replace /79 the supplies of electrical energy in the storage batteries.

As a result of the braking session conducted on the 15th of November, the "Luna-17" station entered selenocentric orbit with the following parameters: altitude above the surface of the Moon — 85 kilometers;

- inclination of the orbit to the plane of the lunar equator — 140°;

- period of rotation around the Moon — 1 hour 56 minutes.

A new and important stage in the flight of the station had come. It was necessary by carrying out careful trajectory measurements to establish the precise values of the orbital parameters of the station, by carrying out calculations for making corrections in order to develop an orbit for landing.

At this time, the operators, engineers and mathematicians worked under great stress at the coordination-computer center and at the measurement stations. The original data for the maneuver were obtained. They were transmitted over radio links in the form of codograms to the station and to the memory devices in the control system. On the 16th of November, as the result of a successful accomplishment of the maneuver, the station shifted from a circular orbit to an elliptical one. As the subsequent trajectory measurements showed, the parameters of the new selenocentric orbit were close to the calculated ones, so that the value for perilune (minimum distance from the surface) was 19 kilometers. /80

The flight of the station was nearly complete. The onboard and ground radio systems were operating at full capacity during the brief "windows" of radiovisibility, picking up telemetric information from onboard stations concerning the function of the systems and transmitting the landing program to the craft.

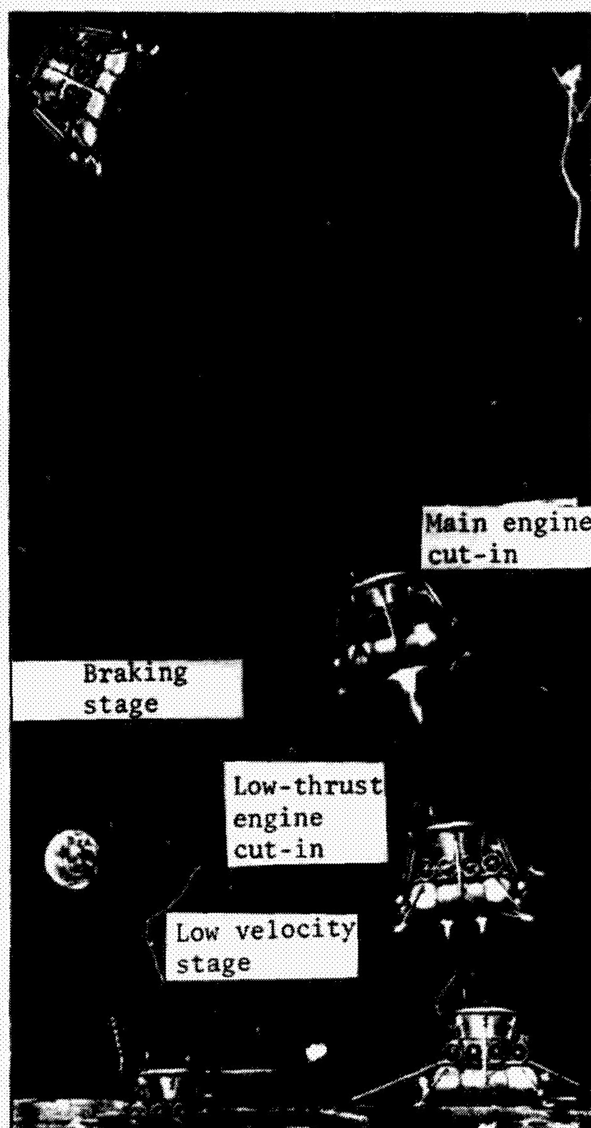


Diagram of the Landing of the "Luna-17" Station on the Moon.

Two stages of the flight of spacecraft, making a landing on the Earth, the Moon or on some planet in the solar system after completing a flight, are very similar in complexity and difficulty to the flights of aircraft, especially experimental ones. These two stages are takeoff and landing. But there is a fundamental difference. Even if the aircraft makes a landing completely automatically, the pilot still has the opportunity to intervene if necessary in controlling the aircraft and the engineers who control the flight of spacecrafts from Earth as a rule are deprived of this possibility. The processes that occur during the landing take place too rapidly and the distances are so great: it is 400,000 kilometers to the Moon, 60 to 70 million kilometers to Venus and about 150 million kilometers to Mars. The command is delayed, and the ionized cloud which surrounds the spacecraft as it enters the atmosphere (Venus, Mars) does not allow the radio signals to pass through. Therefore, the success of the flight is entirely dependent upon the functioning of automatic devices.

On 17 November 1970, at 0553:40 Moscow time the "Luna-17" station came out from behind the disc of the Moon for the 28th time. All of the systems aboard the station were ready to carry out the landing maneuver. The astroorientation and control systems were working properly. The radio reports concerning the operations performed were laconic and clear. The station was oriented with respect to the Sun and the Earth and the programmed turn had been made. The suspension elements were discarded! The braking engine was prepared for operation and the independent radio devices used in landing (high altitude radio altimeter, Doppler apparatus and low altitude altimeter) were ready. /81

"Luna-17" Automatic Station Makes A Soft Landing (Frame From a Motion Picture).

On 17 November at 0641 the braking engine assembly of the unified landing stage was cut in and the station descended from orbit around the Moon.

Obeying the commands of the control system, following the landing program, the station approached the lunar surface.

At 0647 the landing devices touched the lunar surface, took up the shock and the station came to a halt.

The address of the "Luna-17" station was Mare Imbrium, 38° 17 ' N and 35° W.

However, the exquisitely performed landing of the automatic station in the set region of the lunar surface was an important but only preliminary stage of the flight.

The complex and unique experiment lay ahead.

Across the Expanses of the Moon

After the "Luna-17" station landed, the tension at the coordination-computer center, at the remote space communication center and at the "Lunokhod" control station not only failed to decrease but even increased.

The only question in which everyone was interested was whether or not the "Lunokhod" would or would not work.

It was all right to be excited, but the ongoing program had to be carried out.

Slowly the operators began to carefully check the entire "Lunokhod", system by system.

By means of pyrotechnic devices, the hinged supports separated and the platform sat with its tanks on the lunar surface. The inclination (left and right) and list (tilting forward and back) was normal — no more than 2 to 3°.

The temperature in the hermetically sealed compartment was 18° Celsius and the pressure was 780 mm mercury.

The narrow-beam antenna, used for transmission of television images, was oriented toward the Earth. The onboard and ground apparatus for television transmission was adjusted.

The next command was given to the station; the pyrotechnic clamps opened which had firmly held the "Lunokhod" on the middle portions of the ramps. Smoothly, as they had done during the tests, the ramps unfolded and lowered to the surface of the Moon.

The way was open for the "Lunokhod-1", the first to travel over the surface of the Moon!

But we must check and decide in which direction the descent should take place.

The television devices were switched on. Telephotometers examined the wheels, ramps, elements of design and portions of the lunar surface ahead of the ramps, the first craters and the first stones.

The telephotometer continued scanning, and the image of the flag of the Soviet Union appeared in the field of vision, mounted on the support for the /82
landing stage. The hammer and sickle were clearly visible. The telephotometer turned further and there was the pentagonal pennant with a bas-relief of V. I. Lenin.

This remarkable feat had taken place one hundred years after the birth of the leader of the Soviet people and the Communist Party.

The telephotometers finished their examination. The "eyes" of the "Lunokhod" began to function — the slow scan television cameras.

The screens of the monitors showed an image of the ramp and the surface of the Moon.

The decision was made to descend from the landing platform in a forward direction. The commander of the crew gave the order: "Go!" Like an echo in the hushed room, the answer of the operator came back: "It's moving!" And the "Lunokhod", obeying the human wheel which controlled it, although that human was 400,000 kilometers away, rolled down the ramp. The front wheels touched the lunar surface and the command came: "Stop!" It was necessary to look around again. To find out how deeply the front wheels had sunk into the ground. How fast to travel. It is easy to understand the caution with which the control group was working. For the first time, an independent automatic device was going to travel around on the Moon.

The examination was completed and the command was given: "Start moving in first gear." Again the "Lunokhod" sprang into life, began moving, and all eight wheels touched the lunar surface. This took place on the 18th of November 1970, at 0928 Moscow time.

The "Lunokhod-1" was the first to put its wheels on the lunar expanses! There the "Lunokhod" was, standing firmly on the surface of the Moon. But what kind of a surface was it, how hard was it? Might it sink?

The firmness of the ground was determined by means of an instrument for testing the hardness. The data from telemetric information were decoded and reported to the commander of the crew. There was no danger; the "Lunokhod" could go on.

Every meter traveled, every turn, every climb and descent was recorded by instruments and the driver plotted this route on a map and entered on it all the craters, depressions and stones which were encountered on the way. In this fashion, the first large scale map of the route covered on the Moon was prepared.

In addition to marking down the route, the navigator was supposed to maintain the set direction of movement and lay out the road, in accordance with the lunar situation.

The operator of the narrow-beam antenna carefully followed the signal level coming from the "Lunokhod" and when it decreased he would trim the antenna of the "Lunokhod" so that it pointed toward Earth again and thus made it possible to obtain high quality television pictures.

The engineer received all the telemetric information about the functioning of all the systems aboard the "Lunokhod", and he worked together with the specialists to select the best operating mode and the best speed to use.

The first 20 meters had been covered. The first zigs and zags had been /83
made. Scientific information had been received. Panoramas of the lunar surface had been transmitted, and the distinctive landscape was broken by deep furrows with tire tracks in them!

The first driving session was over. The lid of the solar battery was opened and the "Lunokhod" turned around to get in the best position for obtaining electrical energy (it aimed toward the Sun, and the surface of the solar battery was at an angle of approximately 90°).

The automatic self-propelled laboratory had arrived to carry out the program of scientific research in Mare Imbrium.

Why Mare Imbrium?

The reader may wonder why Mare Imbrium was chosen for the studies, a region which is located where there is a transition from the flat surface of the Mare floor to mountainous areas.

Mare Imbrium has long attracted the attention of astronomers of all countries and there are many hypotheses concerning its origin. Here are some of them.

In the distant past there was a collision between the Moon and an asteroid, which was moving at a comparatively low velocity — approximately 3 kilometers per second, and the asteroid was moving at a large angle to the vertical. As a result of the collision, the surface layers of the Moon were disturbed and mountain chains were created around the giant crater, approximately 700 kilometers in diameter; these mountain chains have since received the names of the Carpathians, Apennines, Caucasus, Alps and Jura.

The molten lava, which was ejected from the core of the Moon, filled the bottom of the crater and formed Mare Imbrium.

Another thypothesis says that Mare Imbrium was formed as a result of the collision between the Moon and the nucleus of a comet. As a result of the colossal explosion, an enormous part of the lunar surface was melted and formed Mare Imbrium after it hardened.

A number of hypotheses explained the origin of Mare Imbrium by tectonic processes occurring in the bowels of the Moon, while others attribute it to internal processes associated with the decay of radioactive substances. There is no lack of hypotheses, but there is nothing definite either.

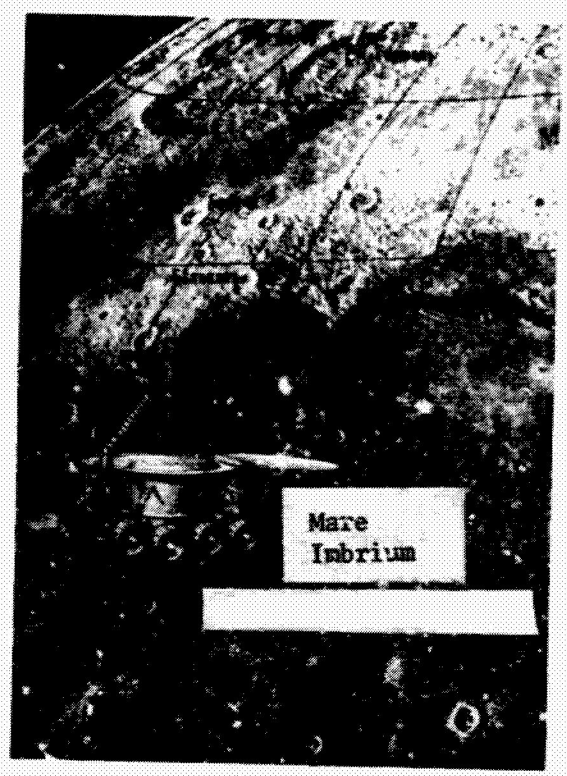
Aside from anything else, Mare Imbrium attracted the attention of ballisticians and of course geologists. An analysis of the movement of the artificial satellites of the Moon led to the detection of a strange and interesting phenomenon that has not yet been explained by science. As the satellites flew over the flat areas of the annular seas their velocity increased, as if the attraction of the Moon had increased at these places. These anomalies in the gravitational field of the Moon have been called mascons.

The nature of the mascons can still only be theorized about. It is possible that in these areas there is a mass of materials with increased density at a comparatively shallow depth beneath the surface of the Moon. For example, meteoritic iron or iron-titanium ore, or something else.

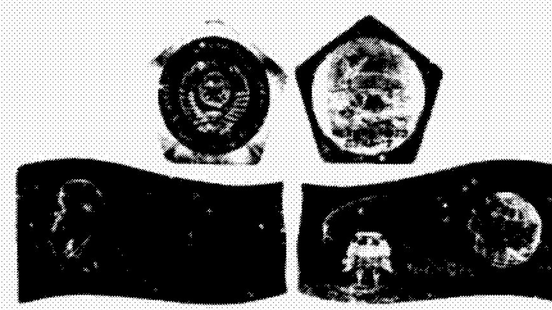
In view of the fact that Mare Imbrium is the largest of the annular seas and the typical features of all lunar annular seas are most clearly evident in it, its study for the purpose of solving questions of the structure and evolution of the Moon was most advantageous.

Experience in studying the Earth has shown that the most promising regions for studies aimed at understanding the geological structure and processes of evolution on the surface in the bowels of the planetary body are the zones of transition from one kind of structural zone to another. In the case of the Moon, such regions are the "coastal" bands where there is a transition from /85
the Mare plains to mountainous formations.

This is far from a complete list of the reasons why Mare Imbrium was chosen as the landing site for the "Lunokhod-1".



Landing Site of the "Luna-17" Station, Which Brought the "Lunokhod-1" Self-propelled Apparatus to the Surface of the Moon.



Pennants, Mounted on the "Lunokhod-1"

Day One

Let us start right off by saying we are talking about a lunar day, which lasts 14.5 Earth days.

As we already know, the "Luna-17" station landed in Mare Imbrium on the 17th of November. At this time, it was lunar noon at the landing site of the station. The lifeless, motionless burning lunar desert, dotted by thousands of craters, surrounded the "Lunokhod-1" on all sides.

The first hundreds of meters traveled across the lunar potholes were rough on both the "Lunokhod" and the individuals controlling it.

A mistake that was made during training at the lunodrome could be easily corrected, but here it was something else entirely — all of the responsibility for the "life" of the "Lunokhod" rested on the group controlling it.

The people learned — and the "Lunokhod" too learned to travel on the Moon, carrying out those scientific experiments that were prescribed by the program.

The first 20 meters had been covered. This was both a great deal and only a little bit. But there was no reason to be bitter — there were still many days of traveling ahead.

On the night of the 18-19 November the "Lunokhod" had traveled 96 meters and during this communication session it transmitted to Earth several panoramas of the lunar surface, determined the mechanical properties of the soil at several points and used its x-ray telescope to measure the background of extragalactic x-radiation.

One after the other, the scientific instruments and systems went to work doing their research.

The third day of the stay on the Moon began. The zone of radiovisibility had come into view. The crew took their places at the control panels. And again the "Lunokhod" lurched into motion, traveling across small craters, going around steep slopes and obstacles, heading south. Eighty-two meters were covered, less than yesterday. But some valuable research had been done, the chemical composition of the soil and its mechanical properties had been ascertained. These experiments can only be carried out while the machine is standing still, so that the first of these experiments took considerable time.

When the next communication session was over, what would be next on the schedule? At a meeting of the operator group, it was suggested to start getting the "Lunokhod" ready for the lunar night. This was a new and serious step in the "life" of the automatic apparatus. It had passed the test of the "hot" lunar day with flying colors; how would it deal with the "cold" lunar night?

How was it prepared for the night?

The following had to be done:

the chemical power supplies had to be fully charged; /86

a flat place for parking had to be found.

The "Lunokhod" had to be parked at the selected area in such a way that, first of all, the laser reflector would be oriented toward the Earth and secondly that when the Sun rose in the lunar morning its rays would strike the solar batteries without interference and charge the chemical power sources.

The lid of the "Lunokhod" would have to be closed, with the solar battery on the inside;

in order to save the electrical energy supplies, all systems of the "Lunokhod" would be shut down except for the standby system — the radio receiver and the temperature regulating system.

On 21 and 22 November, during the radio communication sessions, all of the above operations were carried out and as the night of the 24th November came on the "Lunokhod" went to "sleep" in Mare Imbrium. For five days the first automatic self-propelled research vehicle had been actively at work on the surface of the Moon. Particular emphasis had been placed on testing the drive system of the "Lunokhod" and all of its onboard systems.

The "Lunokhod" had demonstrated good maneuverability, good handling and good functional characteristics.

During the driving tests a method had been developed for driving the automatic device on command from Earth by means of television and telephotometric images of the lunar surface.

The "Lunokhod" had covered a distance of 197 meters in the course of its travels.

The television and telephotometric images of the lunar surface that were received during the ten communication sessions were of good quality. On the basis of these pictures, one could get an idea of the characteristics of the structure and form of the lunar surface along the route covered by the "Lunokhod", the relief and the lunar landscape as well as the results of the contact between the wheels of the chassis and the ground.

The experiments that had been performed confirmed the correctness of the technical solutions that had been adopted in designing, building and developing the individual systems and the "Lunokhod" as a whole.

At the same time that the drive mechanisms and systems of the automatic device were being tested, complicated scientific investigations involving a study of lunar physics and space were carried out. By means of a radiometer, the penetrating radiation was measured and the radiation situation on the surface of the Moon was checked. The fluxes of protons, electrons and alpha particles, cosmic radiation, and angular distribution of low-energy protons were all recorded.

The x-ray telescope measured the intensity and angular distribution of the x-rays of extragalactic background and the radiations from individual sources.

The first measurements of the intensity of galactic cosmic rays, carried out by the "Lunokhod" on the surface of the Moon, showed that their intensity decreased approximately 60% in comparison with the value recorded during the /87
flight. This phenomenon may be explained by the shielding effect of the Moon. At the same time, this fact confirms the conclusions that were made as the result of the flights of the "Luna-9" and "Luna-13" stations, regarding the low radioactivity of the surface of the Moon.

During the period from the 17th to the 20th of November all of the detectors of the radiometer, mounted on the "Lunokhod", suddenly indicated an increase in the number of solar protons, electrons and alpha particles. At the same time, this phenomenon was picked up by the apparatus mounted on the "Venera-7" station which was about 30 million kilometers distant from "Lunokhod-1."

As an analysis revealed, this was caused by a solar flare on 19 November 1970.

It must be pointed out that from the very beginning of the flight of the "Luna-17" the fluxes of protons with energies in the 1-5 million electron volt range were recorded, which are considerably greater than the average background fluxes of these particles in interplanetary space. Their intensity slowly decreased during the entire period of the flight toward the Moon, by a factor of approximately 5. At the same time, the normal level was determined and there were small variations in the protons of galactic cosmic radiation with energies exceeding 30 million electron volts.

Analyzing these two phenomena, scientists concluded that they had recorded the last phase of the decrease in intensity of solar protons following the end of a large flare on the Sun that had occurred on 5 November 1970.

Along various segments of the path studies had been made of the mechanical properties of the lunar soil and the chemical composition of the surface layer of the bedrock had been determined.

On the basis of telephotometric and television pictures of the lunar surface, and also on the basis of the indications of onboard navigation devices and the calculations of the navigator, the first large scale topographic chart was plotted along the path covered by the "Lunokhod".

The program of research for the first lunar day had been completely carried out.

During the lunar night, which lasted from 24 November to 8 December 1970, two radio communication sessions with the "Lunokhod" were held. The data on telemetric information confirmed that all systems of the "Lunokhod" were in working condition, and the pressure and temperature in the hermetically sealed compartment were within the specified limits – approximately 760 mm mercury and 16° Celsius when the temperature on the surface of the Moon was below -150° Celsius.

On the 5th and 6th of December, as the morning terminator approached the area where the "Lunokhod" was standing, and when it was possible to aim the telescope accurately on the basis of the visual characteristics of the lunar formations, experiments with laser location were performed. The ground apparatus at the Crimean Astrophysical Observatory of the Academy of Sciences of the USSR was aimed at the Moon and clearly reflected signals were recorded /88
from the laser reflector mounted on the "Lunokhod" which, as we have already mentioned, was built by French specialists.

A similar experiment was carried out by French scientists at the Pic du Midi Observatory.

Day Two

On the 9th of December 1970, after the "Lunokhod" had "warmed up" in the rays of the rising sun, radio commands were transmitted to it which prepared the "Lunokhod" for the next work day.

Although the telemetric information conveyed data to the operators which indicated that the "Lunokhod" had withstood the test of the lunar night successfully, everyone wanted to see and be sure that the "Lunokhod" would start up again.

On command, the lid of the "Lunokhod" opened and the first rays of the Sun struck the solar battery. In the operations room of the Center for Remote Space Communications, a clear and happy piece of news was issued — "the current in the solar batteries is normal — 3 amperes!".

The battery charging session began. After a short time, the functioning of the television and telephotometric apparatus was carried out. The panoramas obtained as a result of these tests clearly showed the lunar surface, the tracks of the wheels, elements of the structure of the self-propelled device and the image of the Sun rising over the lunar horizon in the black sky of space.

The 10th of December had come, the supplies of electrical energy had been fully replaced in the storage battery, and the vehicle could now get underway.

What would the scientific laboratory do on this day?

It was decided to do the following:

to investigate the lunar surface over a distance extending approximately 1-1/2 kilometers;

to determine the regularity of distribution of craters by diameter, depth, steepness of slopes and age, and to try to determine their origin;

to carry out a determination of the number of stones on the lunar surface and their classification;

to continue the investigation of the chemical and mechanical properties of the lunar rocks (surface layer), and also x-ray studies of cosmic rays;

to work out a method of laying out the route and driving the "Lunokhod" under different conditions.

On the 10th of December the automatic self-propelled scientific laboratory left its parking place and laid out a new road 244 meters to the south! This was 25% greater than the distance covered by the "Lunokhod" during all five of the terrestrial days.

But this route was very difficult. Suffice it to say that on the way a crater 16 to 18 meters was encountered which did not appear difficult to cross because of unfavorable illumination. But the defenses broke down as it was being crossed, and the "Lunokhod" came to a stop because the slope reached 27 degrees and the list was 17 degrees. It was only after switching off the protection that it was possible to get the "Lunokhod" out of this quite unpleasant situation. /89

On its way the "Lunokhod" encountered many craters and stones and crossed some of these obstacles while going around others.

Every 20 meters the soil was tested mechanically and the chemical composition was determined in the most interesting places. The density of the soil was 1-1.2 kg/cm^2 on the average.

Nine telephotometric panoramas were transmitted from the scientific laboratory to Earth. It was found that in the majority of craters examined the edge and the walls were as smooth as the majority of rocks, i.e., these craters and rocks were of ancient origin. In addition, in view of the fact that the stones lie on top of a comparatively flat surface, it may be assumed that they were flung there during the formation of larger craters.

However, in the case of individual craters and stones, the edges were as sharp as the tracks left by the wheels on the surface. This indicates that the craters and stones of this kind are "young" and that the process of formation of the lunar surface is going on at the present time, although the paths of evolution on the Moon and on the Earth are different.

Suffice it to say that according to the calculations of scientists an average of 3 meteorites the size of a fist land in one hour in one square kilometer. For this reason, obviously, the surface of the Moon resembles the face of a man who has suffered from smallpox, and the surface layer is composed of basalt rock which has been transformed by meteoritic bombardment and cosmic rays into finely dispersed regolith.

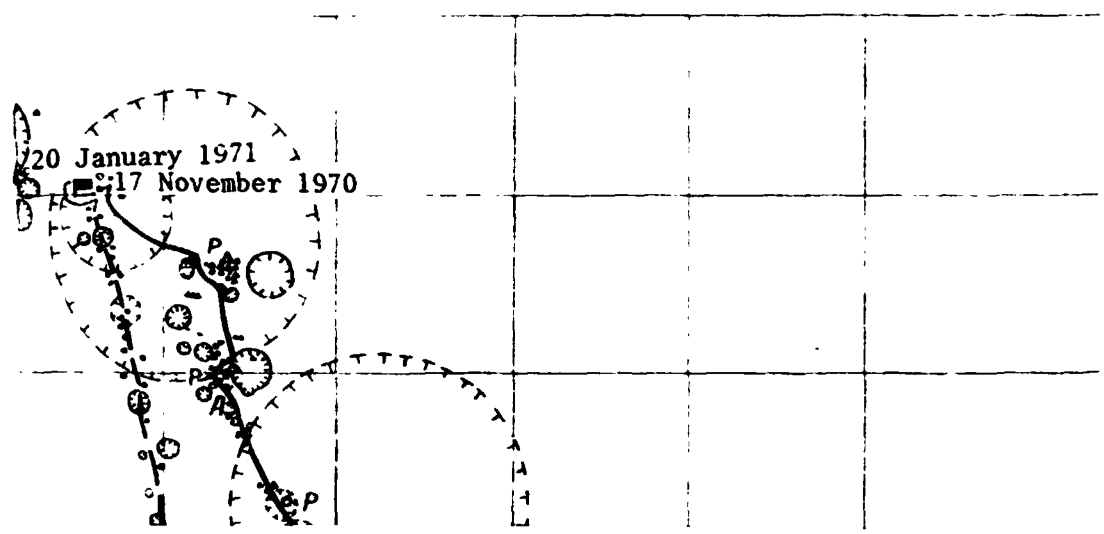
The x-ray telescope continued to scan the sky, looking for sources of radiation in it.

On the 11th of December work was directed toward problems of developing a method of maneuvering and determining the mechanical properties of the soil. It is interesting to note one of the characteristic conditions that prevail on the Moon. While measuring the temperature of the wheels it was found that the wheels that were in the rays of the Sun were heated to a temperature of about +100° Celsius while the wheels that were in the shade had a temperature of -30° Celsius. This is due to the vacuum; it is difficult to create such conditions on Earth. During the next communication session, which began on the 12th and ended on the 13th of December, travel toward the south continued.

In 3 days of travel, the "Lunokhod" had gone 600 meters away from the landing platform and had covered 822 meters across the rough virgin soil of the Moon.

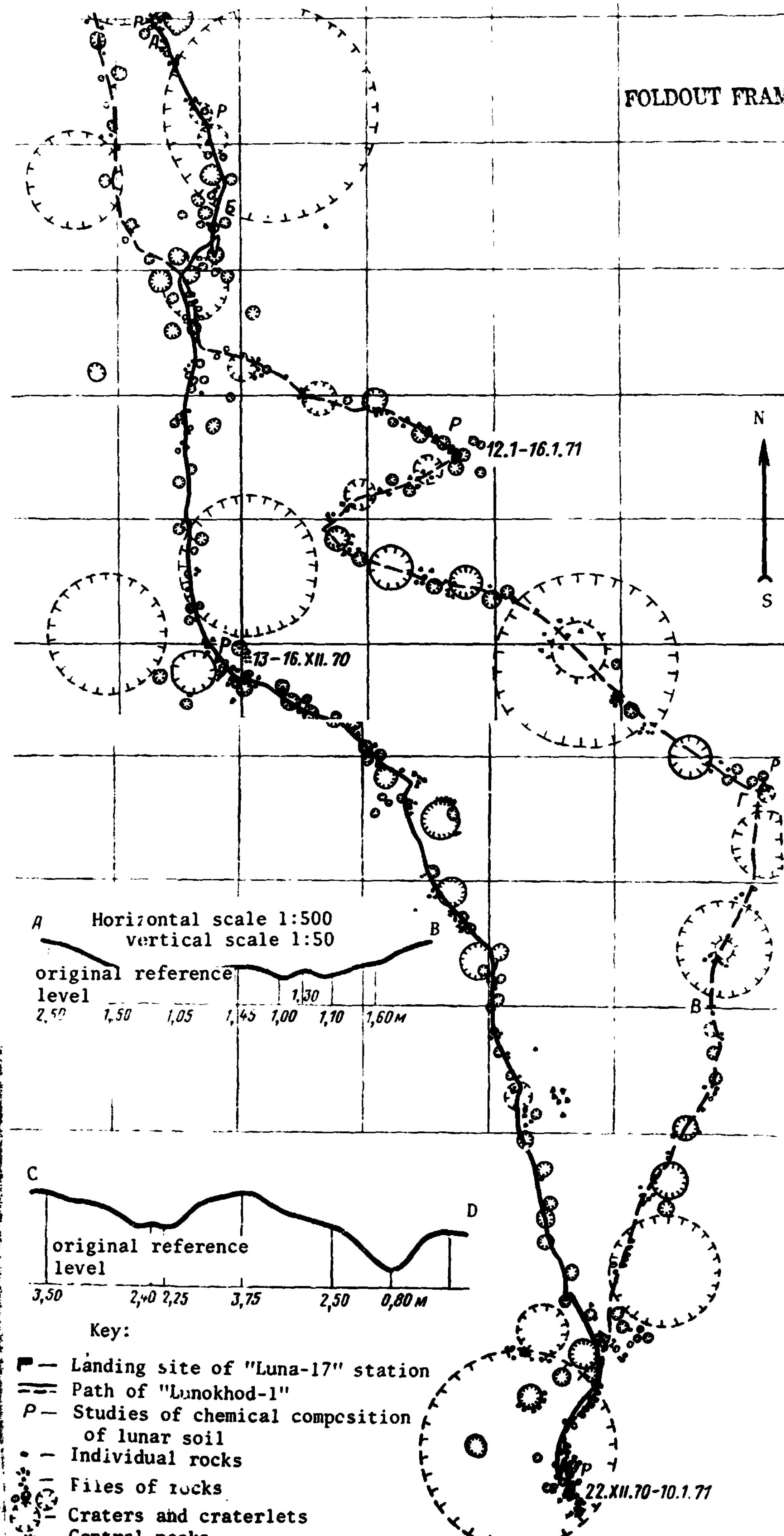
On these days the spectrometer, in addition to its basic functions (investigation of the chemical composition of the soil) became an indicator and recorder for the increase of the intensity of corpuscular fluxes of cosmic /92
rays, increasing the background level by approximately 100 thousandfold, and also a decrease in the intensity of galactic cosmic radiation, which occurred afterward on the 14th of December.

FOLDOUT FRAME



Path of Movement of "Lunokhod-1" on the Surface of the Moon. /90,91

FOLDOUT FRAME 2



At this time on Earth violent magnetic storms were being observed. It should be pointed out that the increase in the intensity of corpuscular fluxes was recorded by an apparatus which is similar to that which was mounted aboard the "Venera-7" interplanetary station, on the "Intercosmos-4" satellite and by the ground stations monitoring the Sun.

The measurements performed by the "Lunokhod" were carried out primarily in the range of energies which cannot be received on Earth due to the screening effect of the atmosphere.

All of the phenomena described above, as we mentioned earlier, were caused by a series of strong flares on the Sun, which took place on the 10th and 11th of December.

The Sun's disc slowly but steadily rose higher and higher over the lunar horizon, flooding the lunar surface with blinding light. Even without this, it was a difficult task to get oriented in the area, select the direction for movement and recognize obstacles.

There were practically no shadows which could be used for determining where the obstacles lay. Under these conditions, as the "Lunokhod" moved along it was easy for it to fall into a situation that it might not escape from. Therefore it was decided not to move between the 14th and the 17th of December, but to carry out experiments and research with the "Lunokhod" stationary.

The lunar noon came, the hottest time, the temperature on the panels of the solar batteries reached almost 140° Celsius, while on the wheels that faced the Sun it was somewhat lower — 100°, but the temperature inside the "Lunokhod" was only +18°. The temperature regulation system was functioning normally.

It is interesting to note that the radiator in the cold circuit, mounted on the top of the hermetically sealed container, although it was in full sunlight, was practically unheated thanks to a special covering that had certain optical coefficients.

In the night of the 17th-18th December, during the routine communication session, the "Lunokhod" traveled 197 meters and left behind it a trail measuring a total of 1,022 meters.

The first kilometer had been covered!

Remember the first 10 meters of the journey, how difficult they seemed!

But now the crew had mastered the technique of driving, they had learned how to determine the most interesting (for science) and passable routes in the terrain and drove the "Lunokhod" confidently over the lunar surface.

At the end of the session the "Lunokhod" encountered a crater about 20 meters in diameter in its path, having a slope of about 20 degrees, and descended into it. On the bottom of the crater it found a pile of stones, which led to the decision to leave the "Lunokhod" in the crater until the next session.

This session began on 19 December at 0000 Moscow time. Emerging from the crater, the "Lunokhod" continued moving forward, southward. When it encountered craters with a slope of less than 23 degrees, the "Lunokhod" crossed them at angles of list up to 18 degrees, but went around larger ones. /93

As it moved along, it measured the distance it had traveled and conducted measurements of the physical and mechanical properties of the soil during brief halts.

After traveling 263 meters during the session, the "Lunokhod" was 1,000 meters distant from the landing platform.

After the automatic self-propelled apparatus was brought to a halt, a chemical analysis of the composition of the soil was performed and telephoto-panoramas of the surrounding terrain were transmitted to Earth. The Earth could be seen in one of them. From this and from the position of the Sun the navigators were able to determine the selenographic coordinates of the "Lunokhod."

The 20th of December came. It was 0426 Moscow time. The operators and the crew of the "Lunokhod" took their accustomed places behind the control panels at the Center for Remote Space Communication. They gave the usual commands and a new working session began for the "Lunokhod."

The crew of the "Lunokhod" began to feel a strange sensation: they began to feel that they were there. It seemed to them that they were not in the hall but there on the Moon, 400,000 kilometers from Earth. This psychological factor obviously can be explained by the skill, previous experience and confidence of the crew.

At the beginning of the new session the "Lunokhod" emerged from the edge of a shallow depression and began to move along it in a southerly direction.

The path of its travel lay along the plain with a great many small craters on it. Occasionally there were piles of stones, measuring up to 15 to 20 cm.

At the end of the session the automatic device encountered a large crater with a diameter of approximately 100 meters and a depth of 8 to 10 meters. It was decided to examine it carefully. After descending to the bottom of the crater, panoramas of the surrounding terrain were taken, in which small craters could be seen as well as piles of rather large sharp-angled (i.e., "young") stones measuring 20 to 30 cm.

Three hundred and thirty-seven meters were covered during the session. Measurements of the physical and mechanical properties of the soil were carried out systematically. Considerable interest attached to the measurements that were carried out on the inner slopes and on the bottom of the large crater where the "Lunokhod" stopped.

During this session, the memory unit transmitted information to Earth concerning the fluxes of radiation coming from sources located in the plane of the Galaxy and detected by the x-ray telescope.

On the basis of the data from the radiometric measurements it was confirmed that during the last few days there had been no significant increase in the intensity of corpuscular cosmic radiation. Background radiation was in accordance with the radiation situation that characterizes a period of a quiet Sun.

On the 21st of December the crater in which the communication session of 20 December had been interrupted again became an area for research. /94

The "Lunokhod" completed its movement across the bottom of the crater and along its slopes, examining individual stones and piles of stones, as well as smaller craters which were present in great numbers on the bottom of the large crater.

Although the "Lunokhod" covered a total of 78 meters during this session, it executed twice as many maneuvers as it did in the previous session.

The program of investigation for the second day was carried out fully and it was necessary to think about selecting a parking place for the second lunar night and to prepare for it.

All of the operations involved in preparation for the lunar night, which would come on the 24th of December 1970 and would last until 9 January 1971, were carried out during the communication sessions on 22 and 23 December.

The second working day of the "Lunokhod", lasting from 9 to 23 December 1970, had been successfully completed.

In accordance with the designated program the automatic apparatus had traveled 1-1/2 kilometers over the surface of the Moon at the same average velocity that it had had during tests at the lunodrome at Earth. The coefficient of useful energy utilization during movement was close to unity. The result was very high even for terrestrial conditions. As it traveled the "Lunokhod" not only encountered approximately 40 craters but investigated them. Stones that were encountered on the way were subjected to the same careful investigation as the craters.

Why was such great attention given to studying craters and stones?

It is a fact that the morphological characteristics of clearly outlined small craters indicate their origin as a result of an explosion. But what kind of an explosion was it — volcanic or meteoritic? If we know the law of distribution of craters over the surface, we can ascertain the cause of the explosion.

The "Lunokhod" will help scientists to answer this question.

Well, and what about the stones? It may now be considered established that their presence on the surface of the Moon is linked primarily to the process of crater formation. The stones are fragments of rocks thrown out onto the surface as the result of explosions.

This makes it possible to determine which rocks are located beneath the surface layer of the lunar regolith and would not be picked up by drilling. From the shape of the stones we can also determine how long ago this process took place.

These studies were also carried out by the "Lunokhod".

At this point it would be a good idea to remind the readers of several characteristics regarding the distribution of craters and stones on the surface of the Moon which have been determined. The law of distribution of craters with diameters from several centimeters to hundreds of meters indicates that the probability of encountering craters of a given diameter is inversely proportional to the square of the diameter. This means that if we choose an area 1 kilometer square in a lunar "sea", there will be approximately 80,000 craters 1 meter in diameter, and only about 800 craters with diameters of more than 10 meters. In the same square kilometer we have found several tens of thousands /95 of stones larger than 20 centimeters in diameter and only 100 stones larger than 2 meters in diameter.

The nature of the movement of the "Lunokhod" is somehow reminiscent of the pioneer geologist. From a high point in the area it looks around and chooses a direction for travel. On flat places it moves rapidly, but stops when encountering a fresh crater or a group of stones, examines them, carries out physical and mechanical tests (this happened 73 times in the course of the second lunar day) and carries out a determination of the chemical composition of the soil at places where there has been an ejection of "fresh" soil.

The preliminary results of the chemical analysis have made it possible to establish the concentration of the basic rock-forming elements in a number of locations where the research was carried out.

The "Lunokhod" discovered aluminum, iron, silicon, titanium, magnesium, potassium, calcium, i.e., essentially the same elements which were found in the sample which was brought back to Earth by the "Luna-16" station.

The x-ray telescope conducted studies of 33 regions in the celestial sphere. The existence of diffuse (i.e., scattered) cosmic ray background was established. However, discrete (individual) sources of cosmic radiation were found. One of the significant discrete sources of x-rays is located in the constellation Sygnus. By means of a radiometer and the "Rifma" instrument the changes in the intensity of the cosmic rays during the solar flare of 10 December were recorded. For the first time, the measurements of this grandiose cosmogonic process involved the use of a number of instruments that were tens of millions of kilometers apart. Very rare and valuable scientific data was obtained which is of enormous significance for explaining the mechanism of this phenomenon.

We should also dwell on still another important result of the studies carried out on the second lunar day. For the first time, directly from the surface of the Moon, its mountainous continental formations could be seen – the mountain Massiff of Cape Heraclitus.

The movement of the "Lunokhod" had enabled an area of 225,000 square meters to be examined, together with a preparation of the profiles of the craters encountered on the way, so that a statistical table of their sizes could be compiled.

It should be emphasized once again that the surface of Mare Imbrium is highly irregular, and although it is 1,000 kilometers away from the equatorial "seas", it is not very different from them. Consequently, the processes of evolution of the lunar surface in both the equatorial zone and at high latitudes are similar.

From the navigator's standpoint, it was extremely difficult to orient one's self in the area which was studied due to the monotonous appearance of the landscape, the lack of characteristic landmarks, and peculiarities of illumination.

During the second lunar day, 15 radio communication sessions were held, during which 40,000 commands were given and carried out, and an enormous volume /96
of telemetric, television and telephotometric information was set.

The "Lunokhod" was now 1,370 meters away from the landing platform and it had covered 1,719 meters.

The second lunar night was now coming on at the place where the "Lunokhod" stood. The isotope "stove" was working properly, as was the temperature regulation system that maintained the necessary temperature conditions within the hermetically sealed compartments of the "Lunokhod".

After beginning its routine "sleep" in 1970, the "Lunokhod" "awoke" in 1971. Between 23 December 1970 and 7 January 1971 (during the lunar night), 3 brief telemetric radio communication sessions were conducted with it to check the condition of the onboard systems.

No defects in the operation of the systems were detected. The reports were laconic. Everything normal onboard!

Day Three

On 8 January, at 0045, when the Sun was 4 degrees above the lunar horizon, the first command was given to disturb the rest of the "Lunokhod".

The lid and solar battery panel opened up and the batteries commenced charging.

The engineers who were responsible for the temperature conditions aboard the "Lunokhod" carefully followed the heating of the chassis, the narrow-beam antenna and the penetrometer. If everything went well, movement could start only after certain temperature levels were reached; if not, there might be some kind of a failure and all of the rest of the experiments would be seriously threatened.

By 1700 on 9 January 1971 the supply of electrical energy in the batteries had been restored and the new work day began.

As you recall, the "Lunokhod" "spent the night" in a large crater, approximately 100 meters in diameter, and there were many stones with sharp edges in the crater. The location of the piles of these stones and their shapes provided a basis for assuming that they were of comparatively recent origin and that they were ejected from a neighboring crater. It was therefore decided to subject these stones to a detailed examination. The "Rifma" went to work to determine their chemical composition and the telephotometers scanned their external appearance minutely.

For 1-1/2 hours the automatic chemical laboratory worked on the Moon. When this experiment was finished the next one began. This involved determining the physical and mechanical properties of the soil and measuring the parameters of attraction and adhesion.

The "Lunokhod" began to move. Initially it traveled back along the old path that it had traveled on the 21st of December 1970. The tracks were /97 clear and the smallest details of the treads were visible.

As it moved along the old path, the automatic apparatus emerged from the crater and headed off in a northeasterly direction.

During the first session of the third lunar day the self-propelled device covered 140 meters.

What sort of a research program was the operator's group to carry out on the third lunar day?

This problem can be formulated as briefly as possible: to return to the landing platform along a new route in 1 lunar day.

The problem was one of navigation, and sole responsibility for solving it rested on the shoulders of the navigators and the computer.

During the two next sessions held on 11 and 12 January 1971, the speed of the "Lunokhod" reached approximately 100 meters an hour. It had never traveled this fast on the Moon before.

On the 11th of January, 517 meters were covered, and 553 meters on the 12th of January. While the 11th of January and a portion of the trip made on the 12th of January lay along comparatively flat areas of Mare Imbrium, the second part of the journey made by the automatic device made on the 12th of January was characterized by the existence of a great many stones and craters ranging in diameter from 3 to 30 meters.

As it moved under these difficult conditions, the "Lunokhod" demonstrated good handling characteristics.

Since the self-propelled apparatus started moving, it had covered 2,930 meters. During the experiment, which was conducted on the 11th and 12th of January, some very interesting medical studies were carried out.

The status of the experiment involving long term driving indicated retention of good working capacity by all members of the crew. As a matter of fact, during these sessions which lasted 5 and 6 hours, there was a complete change of crew members. The rate of work did not decrease at this time. How was this achieved?

According to the observations of the doctors, it was found that the crew which had started the movement session retained its working capacity at the necessary level until the session was over and carried out the designated work program quite successfully.

But it was necessary to establish the possibility of operational entry into the working rhythm by the new crew without interrupting the session, and also to work out the actual method of changing crews, both partly and completely.

It should be pointed out that the change of crews in the course of a long driving session is one of the methods of increasing the reliability of carrying out the program. In the near future, however, when such lunokhods will be working continuously for many days, this kind of a change will be simply unavoidable.

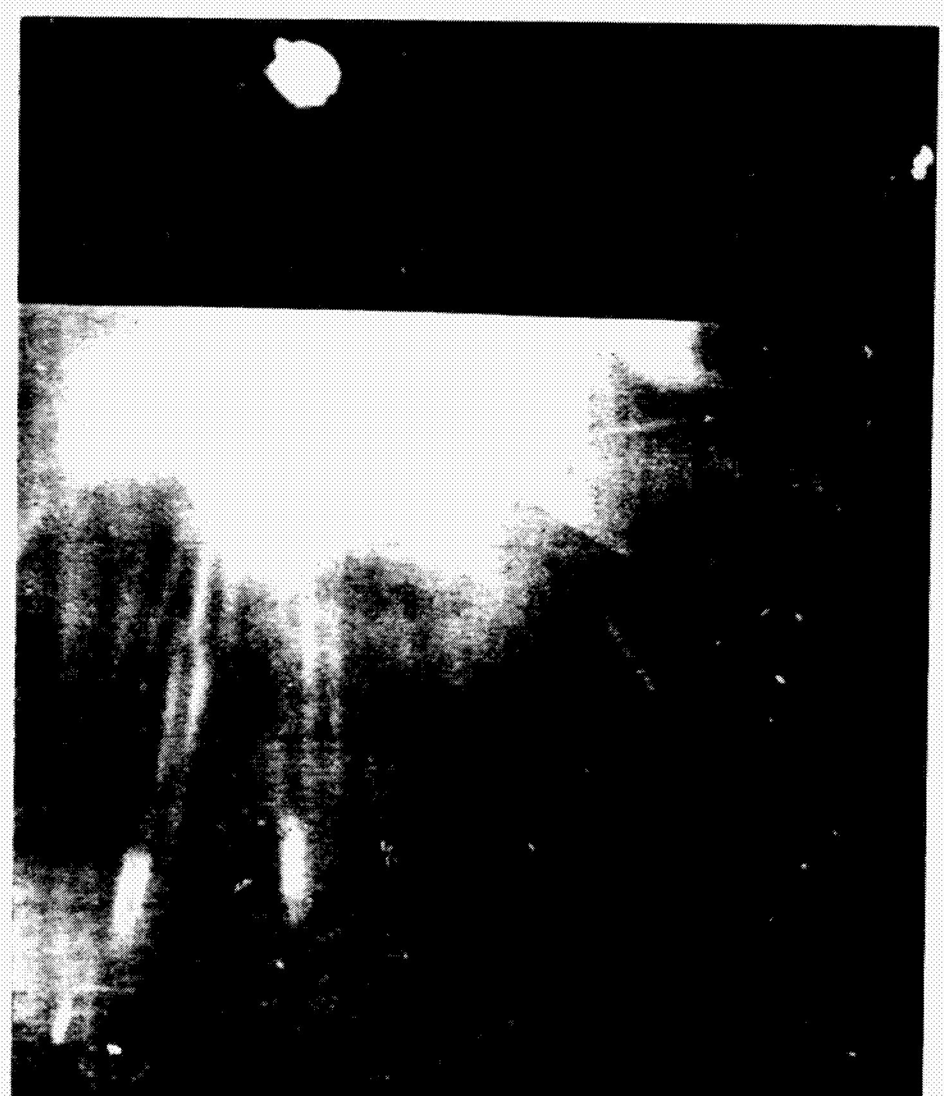
After two days of active driving of the "Lunokhod", it was necessary to carry out a number of scientific experiments and the conditions for orientation and recognition of obstacles deteriorated sharply, which was caused by the elevation of the Sun high above the lunar horizon.

Accordingly, the "Lunokhod" was in a stationary position from 13 to 15 January. During this time, the radiometer, x-ray telescope, and "Rifma" (x-ray spectrometer) were all working. /100

The Sun passed through the zenith and began to set. The visibility improved. Scientific experiments performed in the parked position were terminated. Movement could begin.

During the night from 16 to 17 January 1971 42 communication sessions were held with the "Lunokhod." Movement of the self-propelled device initially lay across a considerably broken terrain, with a great many craters, after which the "Lunokhod" entered a region with a more gentle relief and approached the track which it had made more than a month ago on the surface during its maneuvers on the second lunar day.

The problem of returning the "Lunokhod" to a specific point on its previous route had been solved successfully.



Third Lunar Day. Fragment of panoramic picture taken by telephotometer. Lunar surface brightly illuminated by the slanting rays of the Sun. The tracks are clearly visible. Even the smallest irregularities cast long shadows. On this page, the Sun is visible against the dark background of the lunar sky. /98

[Translator's Note: Caption is the same as for figure on the preceding page.] /99

During this session a total of 254 meters was covered. On 18 January 1971, as movement continued, the navigators brought the "Lunokhod" to the landing stage. In 5 movement sessions on the third day the automatic device had covered the same path that it had traveled in the 2 previous days.

Two months previously the automatic self-propelled device had slowly descended the ramp and set out across the lunar wasteland for the first time. Now, having completed its trip on a circular route, 3,953 meters in circumference, it had headed confidently for the landing platform and had spotted it.

Previously (2 to 3 years ago) such things would have been found only in science fiction, but now there could be seen on the television monitor at the control center and in innumerable photographs in newspapers and magazines.

The "Lunokhod" was nearing the end of the third work day. The Sun was coming closer and closer to the horizon. It was decided that the "Lunokhod" would spend the third lunar night at the landing platform.

On the 19th and 20th of January all preparatory measures were taken and on the 21st of January the automatic device was swallowed up for the third time by the lunar night which lasted until the 7th of February.

What were the principal goals of the third lunar night? What new information did the automatic researcher transmit to Earth?

The principal goal of the experiment which was carried out was to evaluate the accuracy and reliability of the navigation system as well as to check the methods of navigation, remote control and operation of the "Lunokhod."

As we know, this problem was solved successfully. It should be kept in mind that the navigators had no topographic lunar charts (large scale) to plot the course except for a clean sheet of paper.

To carry out these movements and perform scientific research onboard the "Lunokhod", about 3,000 commands had to be given which were carried out without complaint by the "Lunokhod" system.

By means of telephotometers, 13 scanning and 5 astronomical panoramas were transmitted to the Earth. These data were used for topographic and geological- /101
-morphological studies of the lunar surface.

Along the path that was traveled, studies of the physical and mechanical characteristics of the lunar soil were carried out at 200 points. It was found that the soil along the route of the third lunar day had greater hardness than the soil along the route covered on the second day.

The "Lunokhod" successfully crossed 80 craters with rather steep sides, including one with a diameter of approximately 150 meters.

As the result of the activities of the third day, it was demonstrated that self-propelled devices are capable of moving about rather rapidly on the Moon and that the design of the first "Lunokhod" was simple and reliable.

Analyses of the chemical composition of the lunar rocks which were performed during the third day in the course of 8 hours by means of the "Rifma" apparatus provided a rich volume of material which made it possible to conclude that in addition to the elements previously found in Mare Imbrium there was also titanium and chromium.

In the course of the third lunar day, by means of the x-ray telescope, measurements of the x-ray cosmic radiation were continued. Thirty sections of the celestial sphere were examined, located both in the plane of the galaxy and at considerable angles to it. In three areas, fluxes were observed coming from discrete ("point") sources of radiation. The most interesting results of these measurements consist in the fact that some of the areas of the celestial sphere where radiation was recorded coincide with sources of x-radiation as recorded by the telescope on the second lunar day.

The detectors of the "Lunokhod" radiometer continue to record fluxes of corpuscular cosmic radiation.

In contrast to the second lunar day, the third day can be characterized as a day of quiet radiation conditions, with the exception of the 19th and the 20th of January, when an increase in the intensity of the flux of low energy protons by several fold was observed.

Experience in operating the first self-propelled apparatus on the Moon in the course of such a long period of time has provided a wealth of practical information for the design of future machines.

Day Four. The Planned Program of Research Has Been Completed

On 6 February 1971, the blinding disc of the Sun rose into the black lunar sky.

The fourth working day of the "Lunokhod" had begun. Radio commands were given to "wake up" the "Lunokhod" and prepare its systems for operation. The supply of electrical energy required for movement was still inadequate, but the scientific instruments were working — the x-ray telescope and the radiometer. These instruments use the movement of the Moon for "scanning" and /102
collecting information on the x-ray and cosmic radiation which continuously bombard the Moon from various directions.

On 7 February at 1800 Moscow time the communication session began; the purpose of this session was to investigate the optical properties of the area of the lunar surface in question when it was illuminated by the Sun at different angles and to study the possibility of deciphering (recognizing) individual formations under these conditions on the basis of the television and telephotometric pictures.

The performance of this new lunar experiment was not accidental. During one of the sessions aimed at obtaining lunar panoramas at low Sun angles, a formation was spotted in the panorama which had surprisingly rectangular sides, and was of rather considerable dimensions, and the observers had dubbed it the "brick". But image everybody's surprise when during the next communication session it could not be found in the panorama — it had "vanished". The object (formation) that created this optical illusion had not disappeared, of course, but had simply been affected by a change in the illumination conditions and thanks to the remarkable reflectivity of the lunar soil, this area blinded the "television eye" and the object "disappeared".

When studying the lunar soil collected and returned to Earth by the "Luna-16" apparatus, it was found that the surface layer consisted almost 50% of particles that were vitrified or molten, exhibiting distinctive scattering and reflecting properties. In this connection, a desire was expressed to study these properties under the conditions of the natural occurrence of the rocks at various illumination conditions. This experiment made it possible to select the most suitable angles of azimuth and altitude of the Sun at which the "Lunokhod" could move under the best conditions of illumination of the terrain and to check the possibility of the television systems being able to operate under lunar conditions.

If we add to this the tremendous interest on the part of astronomers in knowing the nature of the scattering of light by various portions of the lunar surface, it becomes understandable why it was now necessary to carry out this optical experiment.

Some scientists stated that the Moon simply shines but does not warm up. Their theories went like this: in the first place, as we know, the radiant energy of the Sun heats the lunar surface to +130 Celsius, so that the lunar surface itself becomes a heat radiator. In addition, the x-radiation of the Sun excites the atoms of chemical elements forming the rock (induced radioactivity), so that they begin to radiate energy into space. So, does the Moon get hot or doesn't it?

The optical experiments were performed as follows. A crater with characteristic formations was chosen along the route of the "Lunokhod" and examined on all sides by means of television cameras and telephotometers. During this period of time the position of the Sun remained practically constant /103
as far as altitude was concerned but pictures at different angles of illumination were obtained due to the movement of the "Lunokhod."

Such experiments were repeated many times during subsequent sessions at different places and at different angles of elevation of the Sun. The data from this interesting experiment are being analyzed.

When the optical experiment was complete the "Lunokhod" continued moving north. It had covered 323 meters during the session.

The path of the "Lunokhod" lay across a Mare type surface with craters 30 to 40 meters in diameter. Some of them had steep slopes, up to 15 degrees, and it went through these; it went around others.

On the second half of the trip the automatic self-propelled device entered a zone of ejecta from a large crater, where there were a great many stones of different sizes.

The session was completed by the taking of telephotometric panoramas in which one could see images of the Sun and the landing stage of the "Luna-17" station which at this time was 260 meters distant from the "Lunokhod".

On the 8th of February, beginning at 1800, the "Lunokhod" moved northward for 5 hours in the direction of Cape Heraclitus, which had been spotted in the panoramas taken earlier.

The path of the "Lunokhod" lay across a terrain which was characterized by considerable irregularity due to the great many craters ranging in diameter from 50 to 100 meters.

The session was remarkable by virtue of the fact that the self-propelled device covered its 4th kilometer in traveling across the lunar surface. For the second time the landing stage was hidden from the field of vision of the telephotometer.

A study of the area covered during the session of 8 February was continued on the 9th of February. Several fresh craters ranging in diameter up to 20 meters were seen.

According to the selenologists, one of them was the youngest of all those observed so far. Hence, it was subjected to a careful examination by means of the telephotometers, the "Rifma" instrument (chemical composition) and the penetrometer (physical and mechanical properties of the rock). Measurements were carried out both in the undisturbed layer (regolith) and in regolith with the surface layer removed.

On the basis of the data obtained a detailed geological-morphological diagram of the investigated area was prepared.

It should be pointed out that when we are speaking of comparatively fresh crater or a young one it means that its age is about 2 to 3 million years. On the other hand the age of the rocks making up Mare Imbrium has been estimated to be about 3 billion years.

In accordance with the planned program, during the pauses between communication sessions the radiometer and the x-ray telescope continued scanning the heavens.

By the end of the session on the 9th of February the "Lunokhod" was 578 meters away from its landing platform. On the 8th and 9th of February it traveled 326 meters.

The program of the communication session with the "Lunokhod" on the 10th of February was studied very very actively by the operations group. This depth of attention to the current session was justified by the fact that this was the day when a total solar eclipse would take place on the Moon. /104

This event takes place from 1 to 3 times every year on the Moon. But once every 5 years there is a year without any solar eclipse.

While the Moon is responsible for solar eclipses on Earth, the Earth is responsible for them on the Moon. Since the shadow of the Earth at a distance of 400,000 kilometers is more than 9,000 kilometers in diameter, it is obvious that when the Moon enters it the latter body, having a diameter of approximately 3-1/2 thousand kilometers, is plunged into lunar night conditions for a long period of time (about 3 hours).

The difference between the actual lunar night and the "night" produced by the eclipse is the following. When lunar night comes on, the lunar surface and the "Lunokhod" as well gradually become dark by virtue of the fact that the Sun is slipping behind the horizon (sunset and sunrise on the Moon last about an hour). During the eclipse the shadow races over the lunar surface at a speed of about 4,000 kilometers an hour. Practically speaking, night comes instantaneously. Influx of solar heat ceases and as a result of the low thermal conductivity of lunar rocks the temperature of the lunar surface drops sharply in the course of an hour from +130 to -100° Celsius.

Taking this into account, the question of the temperature conditions aboard the "Lunokhod" was studied carefully. It seemed that everything would be very simple. During the eclipse, the lid containing the solar batteries would be closed, the device would "sleep" for 3 hours, and then the experiment would continue.

But this simple solution could not be carried out, because at the time the eclipse began the "Lunokhod" was outside the zone of radiovisibility of the Center for Remote Space Communications.

The lid could be closed earlier, but then the self-propelled machine with its closed lid would be beneath the boiling rays of the Sun for about 10.5 hours (3 hours before the eclipse and 7 hours afterward). And if the lid were closed, the cold circuit radiator would be located underneath a thick layer of shielding and vacuum insulation and could not carry out its function of radiating heat into space. Consequently, the "Lunokhod" could be killed by overheating.

It was therefore decided to leave the lid (and consequently the solar battery panel) open and to carry out an engineering experiment: to find out how the elements of the solar battery would behave under the conditions of the brief lunar night when the temperature fell to -100° Celsius. Would it withstand such a harsh test or would it break down?

The unusual thing about this experiment was the fact that the "Lunokhod" was in the working position during the lunar night.

Thus, the 10th of February came. At 0940 the Earth shadow raced across the Moon. For more than 3 hours the self-propelled device was exposed to the conditions of lunar night, and it was only 7-1/2 hours after the end of the /105
eclipse that it was possible to communicate with it and find out how the system "felt".

The tests that were performed indicated that under conditions similar to lunar night, for a period of 3 hours, the temperature regulating system had succeeded in completely maintaining the desired thermal regime in the "Lunokhod" compartments. The solar battery had also retained complete working capacity. It was ready to move forward.

On the 10th and 11th of February the "Lunokhod" covered 509 meters. The total path which it covered across the Moon was now 4,813 meters.

During the period from the 12th to the 15th of February scientific measurements were performed in the stationary position. Movement had been suspended due to the fact that the Sun was high above the horizon.

During the next 4 days from the 15th to the 18th of February the "Lunokhod" moved generally northward and covered 411 meters. During this time it carefully examined formations that had been spotted on the 11th of February and had not been previously seen in areas occupied by the lunar Maria.

As we already know, the features of the relief of the lunar Maria include craters with walls, stones or piles of stones, small craters and furrows.

One formation that was found (its dimensions turned out to be much greater than 500 meters) could not be called a crater. Rather, this was composed of distinctive terraces which rose in steps above the rest of the surface of the Mare.

The "Lunokhod" managed to climb up one step, then a second, and then continued moving along a comparatively flat area. It may be assumed that the lava hardened in this fashion after being forced up out of the lunar core onto a comparatively flat surface. As a result, deposits with complicated profiles were formed on the lunar surface.

Hence, our understanding of the microrelief of the lunar Maria has been expanded by means of the "Lunokhod".

Thus, day four had come to and end. On the 19th of February the "Lunokhod" "selected" a place for spending the next night and remained there until the 6th of March.

The Results of Day Four

As reported in the Tass Reports, the planned program for the 3 months of operation of "Lunokhod-1" on the lunar surface had been completed.

The development of an automatic self-propelled device that was the first in history to investigate the Moon by means of automatic devices had opened up the possibility of carrying out scientific experiments not only at the point where the apparatus landed, but as various distances from that point. The total distance covered by the "Lunokhod" in 4 lunar days was 5,228 meters.

The "Lunokhod" made it possible to examine large areas – in 4 lunar days, an area of nearly 300,000 square meters had been studied.

It had been possible to study not only the physical and chemical composition /106 of the cover but also to obtain a great deal of information regarding the structure of the lunar surface thanks to the television pictures transmitted to Earth.

After 4 lunar days, a total of 200 direct measurements of the properties of the soil and in its natural location had been carried out.

Analysis of the data that had been obtained showed that the soil along the route consisted of fine grained material, reminiscent in its basic properties of volcanic sand.

The depth of the friable layer was 6 to 8 centimeters and the upper layer, 1-2 centimeters thick, was more friable and had a weak supporting capacity. The properties of the friable layer were not uniform. The supporting capacity varied within wide limits from 0.2 to 1.1 kg/cm^2. The top layer compacted well and this meant that its carrying capacity was considerably increased.

The resistance of the top layer to rotary cutting was also constant and varied from 0.02 to 0.09 kg/cm^2.

As the result of the interpretation of the spectrograms which were recorded by means of the "Rifma" instrument, the first data were gained on the elements composing the upper layer, individual rocks and in many instances the bedrock. The rocks were found to contain aluminum, calcium, silicon, iron, magnesium, titanium and other elements.

The new data obtained by the "Lunokhod" confirmed the general opinion concerning the origin of the upper layer (regolith) from bedrock of the basalt type and made it possible to determine the changes in the chemical composition as a function of the morphological characteristics of the area in question.

On the basis of the analysis of the television images of the locale, telephotometric panoramas and the data from telemetric measurements of the tilt, list and distance covered, detailed topographic charts of the route were prepared as well as preliminary geological-morphological diagrams of individual regions.

From the nature of the friable surface of the layer, the number of craters and stones, the area of Mare Imbrium which was studied was similar to the previously studied Mare regions of the equatorial zone of the Moon (except for the new formations, the terraces, which were found). This indicates that the processes of formation of the surface of the lunar Maria were the same.

The first data have been obtained on the distribution of craters ranging from 1 to 30 meters in diameter in Mare Imbrium which belong to various morphological classes. It was found that the number of fresh small craters with clearly defined shapes is insignificant in the relief; there is a predominance of craters with smooth shapes of earlier origin.

This indicates that the process of formation of craters is proceeding extremely slowly on the Moon and that the "older" a crater, the softer its shape. In the majority of craters the origin appears to be of a shock-explosive nature.

Stones with rounded edges are older than stones with sharp edges. The /107
occurrence of most stones on the surface have to do with their ejection from a crater; the smaller stones are further from the crater.

Aboard the "Lunokhod", the first experiment aimed at using the Moon as a base for studying the remote regions of the Universe using the x-ray telescope was performed. This is an important new step in the development of extraatmospheric astronomy. Observations performed on the Moon by means of the x-ray telescope have made it possible to carry out prolonged accumulation of signals even from x-ray sources with very low radiation levels.

It was found that the contribution of galactic radiation to the diffuse background is small and that discrete x-ray sources were found which lie outside the plane of the Galaxy. Two of these sources are comparatively strong.

By means of radiometers mounted on the "Lunokhod", interesting data were obtained on the radiation situation on the surface of the Moon, the fluxes of corpuscular radiation, including radiation caused by a series of flares on the Sun which took place on 11 and 12 December 1970.

An interesting fact which confirms the low level of radioactivity of the lunar surface (established previously by the lunar stations) and the screening effect of the body of the Moon is the decrease by approximately a factor of 2 in the intensity of the galactic cosmic radiation following the landing of the "Luna-17" station on the surface of the Moon.

It is important to note that the data from measurements were made by means of the x-ray telescope and the radiometer are of unique significance for science, inasmuch as it was completely impossible to carry out a study of x-ray radiation from Earth because of the existence of the radiation belt, the magnetosphere, ionosphere and atmosphere, while the radiometer mounted on the "Lunokhod" measured the fluxes of cosmic rays primarily in the energy range which is not available to investigation from the Earth due to the shielding action of the atmosphere.

During the lunar nights, sessions involving laser location by means of the angular reflector were carried out, using the instrument manufactured by French scientists and mounted on the "Lunokhod." Clear reflected signals were obtained.

These experiments were performed in order to have precise measurement of the distance from the Earth to the Moon. In addition, the laser location method makes it possible to study the intrinsic rotation and libration of the Moon and to get a precise idea of the position of individual formations on the lunar surface.

The successful performance by the "Lunokhod-1" of its 3 month program including the flight of the "Luna-17" station, soft landing in the specified region of Mare Imbrium, descent of the "Lunokhod" from the landing platform, the 5-kilometer drive over the lunar wasteland, the performance of complex scientific studies, etc. all confirm the correctness of the engineering solutions adopted and the high level of reliability of all of the elements, systems and designs of the "Lunokhod", as well as the ground systems for control and observation. /108

As a result of the successfully performed experiment, the scientists and the engineers had acquired a considerable amount of practical experience in the operation of a mobile scientific laboratory on the Moon and they had gained practical knowledge which was necessary for the development of new automatic apparatus for use in space.

In the course of the 3 month of work in the Moon, all of the onboard systems of the "Lunokhod" had functioned normally. This made it possible for the scientists and the engineers to continue this unique experiment on the Moon.

The Fifth Day of the "Lunokhod" — According to the Supplementary Program

On the 6th of March 1971, the "Lunokhod" greeted the morning for the 5th time. Slowly, the burning disc of the Sun rose above the lifeless horizon.

The onboard radio system received the first command transmitted from Earth and began a new working day for the "Lunokhod", as a result of which a broad supplementary program of scientific and technical experiments was carried out.

At the end of the 4th day, the panoramas showing the path ahead of this self-propelled device had shown an elevation. It was suggested that this was either the wall of a large crater or a hill. According to the program of the 5th day, it was decided that this lunar formation would be investigated.

As a result of observations that had been made, it was confirmed that the "Lunokhod" had reached a crater about 500 meters in diameter and the elevation which was seen at the end of the 4th day was the wall of this crater.

After defining the specifics of the program of research, it was decided to check this crater out in detail.

The "Lunokhod" went around the crater along its northeastern edge. Then the machine descended to the bottom of the crater along the slope. Here there was the wall of the second crater, about 200 meters in diameter, inside the large crater.

The "Lunokhod" crossed the half-kilometer crater over its northern internal slope, emerged at its western limit and descended into the zone of the ejecta of lunar soil at a distance of 150 meters from its edge. In the second half of the fifth lunar day the southern slopes of the large and small craters were studied.

As a result of the analysis of the lunar panoramas, television pictures and telemetric information it was confirmed that the diameter of the large crater was 540 (±20) meters and that of the small one was 240 (±10) meters. The slopes of the large crater had a small angle of about 15 degrees while those of the smaller one were about 20 degrees. The wall of the large crater was blurred and its altitude was no more than 3 to 4 meters, while the small crater had a much more clearly defined wall and its height was 5 to 6 meters.

In the northwestern part of the large crater, a comparatively "young" crater about 30 meters in diameter was found.

Its wall has the characteristic, sharply delineated outline that distinguishes it from the "older" craters and was made up of rocks measuring from 20 to 40 centimeters in diameter. /109

Ejection of these stones could be traced to a distance of up to 90 meters from the edge of the crater. Undoubtedly the craters of this kind were formed as the result of the collision of a meteorite with the lunar surface and their study is of great scientific interest for an understanding of the shock-explosive mechanism of their formation.

It should be pointed out that the movement of the "Lunokhod" was carried out under very unfavorable conditions on this day. As it traveled, the "Lunokhod" encountered obstacles one after the other, in the form of a great many craters ranging in diameter from 1 to 40 meters and piles of stones which were impossible to go around for topographic reasons and the "Lunokhod" had to climb over them.

At these times, the automatic protection of the "Lunokhod" had to be switched off, since the tilt and list angles exceeded the permissible calculated values and reached 25 to 30°.

Regardless of the numerous obstacles posed by the complex topographic conditions of the terrain and the scientific studies that had to be carried out, as a result of which the total time spent moving by the "Lunokhod" during the 5th day was less than on any of the previous days, the distance covered by the self-propelled device was 2,004 meters!

This is more than on any of the preceding days. The average velocity during the movement sessions was about 100 meters an hour. This was possible because of the experience gained by the crew of the "Lunokhod" and the control group, as well as the joint statistical analysis of the various parameters obtained both by means of telemetry and by means of television and telephotometric devices aboard the "Lunokhod".

Thus, for example, in refining the course to be followed by the "Lunokhod" simultaneous attention was given to examining and analyzing the readings of the photogrammetric measurements of the television images of the Sun, solar shadows, local landmarks, and the readings of the sensors which indicated the position of angles of the narrow-beam antenna and the photoelectric Sun sensor.

As a result, there was a reduction of the time expended in moving and considerable increase in the length of the route during each movement session, which also made it possible to increase the length of time used for carrying out scientific experiments.

On the night of the 12th to the 13th of March 1971, the "Lunokhod" covered the 6th kilometer of its lunar drive, unprecedented in the study of space, and on the night from the 18th to the 19th of March it began to travel its 8th kilometer, and by the end of the 5th lunar day (20 March) the total distance covered by this self-propelled machine was 7,232 meters, and the area of the Moon which had been examined measured more than 400,000 square meters!

As a result of the more active operation of all systems of the "Lunokhod" during the fifth lunar day there was a sharp increase in the liberation of /110
heat, and in order to maintain the normal thermal condition within the instrument housing, the supplementary water evaporation system for cooling was turned on for the first time, which successfully withstood its test.

During the fifth lunar day, a wide range of scientific studies were carried out.

At the beginning of the day, astrophysical and cosmophysical studies were carried out, and observations were made of the solar corona and the sunrise.

Over the entire distance that was traveled, there were systematic penetrations of the lunar soil. At the places where the "Lunokhod" stopped, because they were of interest to geologists, studies of the chemical composition of the soil were made. These studies were initially carried out in the area of the surface that was illuminated by the Sun's rays, but later, after the "Lunokhod" had turned around, they were performed on the areas that were shaded by the body of the "Lunokhod."

As a result of these experiments, valuable data were obtained which made it possible for scientists to evaluate the effectiveness of the characteristic radiation of the lunar soil under the influence of solar corpuscular fluxes and to specify the individual characteristics of the spectra of solar and galactic cosmic radiation.

The panoramic telephotometric and television pictures of the lunar surface provided a rich volume of material to selenologists concerning the large new lunar formation, the system of two large craters, which was found on the route of the "Lunokhod".

The television and telemetric information that had been obtained made it possible to determine the precise dimensions and configuration of these craters, the profiles of their slopes, the distribution, shape and exact dimensions of individual characteristic formations within the crater, as well as to put together a morphological description of the region in question.

In addition, the pictures that were taken allowed continuation of the collection of statistical data on the shapes and size of craters and stones found on the lunar surface.

During the lunar noon from 14 to 16 March, when the "Lunokhod" was in a stationary position, cosmophysical studies were carried out and collection of telemetric data on the functioning of the onboard systems was performed.

It was not possible to complete the study of this group of craters and to leave the large crater all in the course of the fifth lunar day. There was too much of interest for scientists that had been found in this region of the lunar surface, bounded by the wall of the 500 meter crater, but the lunar day was drawing to an end.

The "Lunokhod" stopped on the 19th of March for its next "night." Its orientation was carried out, the electrical power supply was charged, and the lid was closed, the Sun set slowly. The fifth night of the "Lunokhod" came and the fifth month of its stay on the Moon began.

The supplementary program of research for the fifth day had been completed in full.

The onboard systems and scientific apparatus of the "Lunokhod" were functioning normally. It is quite natural to wonder at the reliability and /111 working capacity of the drive mechanism of the "Lunokhod", not to mention all of its systems. Four months without any preventive measures or repairs under the most difficult conditions still did not make the "Lunokhod" interrupt its work.

Day Six — Not the Last

Regardless of the good indications of the telemetric information concerning the state of the onboard systems obtained from onboard the "Lunokhod" during the fifth night, the entire control group and the crew waited anxiously for the 6th day and the second one of operation on the supplementary program.

The sun rose on the 6th of April. The lid of the solar battery opened, the electrical power flowed into the batteries, and the "Lunokhod", obeying the will of the crew, again headed out across the lunar wasteland.

The first problem was to escape from the system of two large craters and continue moving in a northwesterly direction.

During the night of the 8th and 9th of April the study of the system of the two large craters which had begun more than 1-1/2 months earlier was completed. During this session the "Lunokhod" left the 200 meter crater, descended the north outer slope of its wall and again climbed up the north inner slope of the 500 meter crater. Moving along the wall of the large crater, the self-propelled device came upon the track that it had left behind on the 5th lunar day. Coming upon this old track made it possible to evaluate once more the accuracy of the navigation system of the "Lunokhod", the navigational skill of the crew and to ascertain with considerable accuracy the location of the apparatus on the lunar surface.

By the end of this session, the path traveled by the "Lunokhod" totalled 7,770 meters.

As an analysis of the telemetric information showed, the radiometer of the "Lunokhod" had recorded a considerable increase in the intensity of corpuscular fluxes of solar cosmic radiation during the period from the 7th to the 10th of April. Thus, on the 7th of April the intensity of the low-energy protons was almost a thousand times greater than the background level. This increase in intensity was caused by a solar flare which took place on the 6th of April and was recorded by ground observatories.

Continuing to move forward, the "Lunokhod" found a new crater on its path during the night of the 10th and 11th of April; because of its unusual shape, this crater was of great interest to the selenologists.

The curvature of the outer slope of the crater, formed by a large accumulation of stones and fragments, was 30 degrees or more.

The ground in front of the crater was also scattered with a large number of stones with a density of distribution that was 80 to 100 times greater than in the flat areas of the lunar Maria that had been studied. Individual stones /112
found along the route measured as much as 3 meters.

In the opinion of the selenologists this crater which had a diameter of several dozen meters was the youngest of all of those found thus far.

It was decided to carry out a complex investigation of the crater using all of the means available aboard the "Lunokhod."

It must be pointed out that the Moon had prepared a surprise for the crew, operators and control group that no one expected. Every meter traveled was literally a battle, and movement was accomplished as a rule with the safety systems of the "Lunokhod" shut off. The steep slopes of the crater, covered by a layer of stones of various sizes and shapes, secondary craters and a friable layer of soil 20 to 30 centimeters thick formed the most incredible and impenetrable labyrinths. The rate of skidding of the wheels in some areas reached 80 to 90%. The "Lunokhod" was encountering these conditions for the first time.

It is important to point out once more the considerable reliability of the drive mechanism of the "Lunokhod", the skill and endurance of the crew, who, under these incredibly difficult conditions, when dangerous situations arose at almost every instant, adopted the correct solutions. Maneuvering among the craters and the stones, sometimes climbing over obstacles, the "Lunokhod" climbed over the outer slope of this crater and descended down the inner slope to the place where the angle of the slope reached a critical value for the self-propelled apparatus. It could not go further. The distance covered along the slopes of the crater to the stopping point was about 100 meters.

After carrying out scientific tests and transmitting a number of television and telephotometric panoramas of the surrounding terrain, the automatic device began to leave the rocky jungle. The crew of the "Lunokhod" handled this problem admirably. On the 13th of April they brought the apparatus out onto the open space between the craters.

In view of the fact that the maneuvering of the "Lunokhod" had taken place in extremely complex co· 'itions of the relief, it was necessary to use up practically all of the electrical energy reserves. Therefore the following solution was adopted: the remaining period of the 6th lunar day would be devoted to replenishing the supplies of electrical energy necessary for the next "night" and the performance of complex investigations with brief movements of the "Lunokhod".

During the 6th day, the self-propelled apparatus had covered 1,029 meters of difficult lunar terrain. The total distance covered since the trip began was 8,261 meters; the distance of the "Lunokhod" from the landing platform was 1,080 meters to the northwest of the landing site.

On the 20th of April, at the place where the "Lunokhod" was parked, the 6th lunar night came on. According to the data from the telemetric information obtained during the next communication session the onboard systems of the "Lunokhod" were retaining normal operating capacity, the pressure in the field compartment was 755 mm of mercury and the temperature was 28° Celsius. /113

If we sum up briefly the investigations carried out by the "Lunokhod" in accordance with the supplementary program during the 5th and 6th lunar days, we can see that a considerable volume of scientific data was collected on the structure of the large craters and stones, and data were also obtained on the characteristics of the surface layer of the lunar soil, the ability of the "Lunokhod" to study the large lunar formations with complex topographic situations, and the method was worked out for carrying out similar studies.

For more than 5 months now the self-propelled device had been investigating the Moon. The volume of scientific information concerning the Moon which was obtained as the result of these studies was 100 times greater than that which had been obtained prior to the "Lunokhod-1" during the preceding studies carried out by means of automatic space devices.

Scientists all over the world gave high marks to the capacity of the automatic self-propelled devices and devices that have returned following performance of studies on the Moon and planets to Earth.

"I am completely convinced that it is on the shoulders of such long lived self-propelled automatic devices as the 'Lunokhod-1' that the principal burden for studying the planets of the solar system will be placed. Such devices, carrying out sampling of the soil and performing many other operations, will open up unique possibilities to investigators.

It seems to me that the exploration of space is especially important for developing a clear idea of the place of man in the Universe. They have already expanded our knowledge regarding the evolution of the solar system, how it arose, developed, and how long it has been in existence. These are not abstract problems but practical ones. Therefore the process of learning, it must be said, will increase enormously in the years to come. It is difficult to imagine now what revolutionary consequences this can have for man in the future..." These are the words of Harry Massy, a professor and chairman of the British National Committee on Space Exploration.

The "Luna-17" automatic station and the "Lunokhod-1" have demonstrated in a most rational and economic fashion the solution of the most complicated problems involving the study of the Moon, planets and space.

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In 1970, Soviet science and technology wrote another bright and outstanding page in the history of the conquest of the Moon and planets of the solar system by means of automatic devices.

For the first time in the history of cosmonautics:

- the "Luna-16" automatic station had returned lunar soil to Earth;

- the "Venus-7" automatic station had descended in the Venusian atmosphere and for 23 minutes had sent back scientific information from the surface of this scorched planet; /114

- the "Luna-17" automatic station had reached the surface of the Moon bringing with it the automatic self-propelled scientific laboratory "Lunokhod-1", which, after successfully carrying out its planned 3 month program of work, carried out a number of additional programs, and is continuing to study the Moon further for several months.

These outstanding achievements of Soviet cosmonautics constitute a success not only for our scientists, engineers, technicians and workers, those who developed, built and ensured the successful flights of these stations and the performance of the unique experiments. This is a success for the entire nation, greeting the 24th Congress of the Communist Party of the Soviet Union by its victories in the field of labor.

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On the 4th of October 1971, the "Lunokhod-1" completed its scientific and engineering-technical studies on the Moon.

Among the experiments that were carried out by the "Lunokhod" during the 6th to 11th lunar days we could mention the following:

- measurements of the characteristics of corpuscular and x-cosmic radiation, performed during the 9th lunar day together with automatic interplanetary stations "Mars-2", "Mars-3" and the "Lunokhod." The results of these measurements are in good agreement with each other;

- measurement of the distance from the Earth to the Moon, the rate at which this distance changes and the angular velocity of the movement of the Moon relative to the Earth. These measurements were conducted in the course of the 9th lunar day by means of ground and onboard radio systems. The results were used in studying the orbital movement of the Moon and its rotation around the common center of mass of the Earth-Moon system;

- a detailed study of the structure of the lunar surface, carried out by means of detailed panoramic photography of the route in the course of the limited movements of the "Lunokhod", made on the 11th lunar day.

The "Lunokhod" had completed its travels among the lunar wastelands. The cessation of the active work of the "Lunokhod-1" was caused by the natural exhaustion of the supply of the isotopic heat source which during the 11th lunar day led to a decrease in the temperature in the instrument compartment below the designated levels.

The successful functioning of the "Lunokhod-1" proved the possibility and feasibility of complex scientific studies of the Moon on planets of the solar system by means of automatic self-propelled scientific laboratories.

The "Lunokhod-1" carried out its research on the surface of the Moon between the 17th of November 1970 and the 4th of October 1971, for 322 days. /115

This unique scientific experiment took place under unusual conditions of a vacuum of space, increased radiation, considerable temperature changes and a complex unknown lunar relief.

All of the programs of research, both the basic one lasting 3 months and the additional one, were carried out completely.

Studies of the Moon and space were carried out during the lunar day and lunar night. The nocturnal sessions, in contrast to the ones in the day, were carried out only with the "Lunokhod" in a stationary position. In addition to the scientific studies, a broad program of engineering and design tests were carried out.

The "Lunokhod" saw the Sun rise on the Moon 11 times. One hundred and seventy-one times, it communicated with Earth. Its wheels left a track 10,540 meters long on the Moon. As it moved along, the physical properties of the lunar soil were ascertained at more than 500 points. Twenty-five times, the rocks forming the surface of the Moon were subjected to chemical analysis. The television cameras of the "Lunokhod" sent back about 25,000 pictures to Earth as the machine moved along, and the telephotometers transmitted more than 200 panoramas of the lunar surface.

Thanks to these experiments, 500,000 square meters of lunar surface were photographed and 80,000 square meters were examined in detail.

In order to develop and analyze the scientific and engineering design data obtained by the means of the "Lunokhod", it will be necessary to work for a long period of time.

New trips to the planets will be aimed at unknown routes to discover the secrets of distant planets. But the "Lunokhod-1" will always remain first among them. It made the first track. It took the first panorama. It made the first scientific studies.

The last signals from "Lunokhod-1" had hardly fallen silent when the signals from the "Luna-19" automatic station, launched on the 28th of September 1971 began to reach Earth from orbit around the Moon; it had entered orbit around our natural satellite as an artificial satellite on the 3rd of October 1971.

The principal purpose of the new automatic station was to carry out scientific studies of the Moon and space near the Moon from the orbit of an artificial lunar satellite.

It is difficult to overestimate the possibilities of artificial satellites in studying heavenly bodies. For example, artificial Earth satellites made it possible to discover its radiation belts, direct data on the composition and properties of the upper atmosphere and space around the Earth were obtained, and new cosmic systems were developed for meteorological and geodetic research.

The satellites have opened up a completely new stage in the study and conquest of the natural resources of Earth. At the present time, it is difficult to imagine how the development of a number of trends in science would /116 have gone had not artificial satellites and the information been obtained from them been available.

By means of lunar satellites, one can:

- study the gravitational field of the Moon and the radiation of the intrinsic radioactivity from its surface layer;

- obtain photographic and phototelevision images of the lunar surface.

- Study the characteristics of space around the Moon.

The first gravitational studies of the field of the Moon have made it possible to detect strong positive anomalies in the force of gravity (mascons) which coincide with annular lunar Maria. The study of this phenomenon, which has not yet been definitely explained, is of considerable scientific interest.

The first studies are the radioactivity of the lunar surface are carried out by the "Luna-10" station and continued by the "Luna-12" station by means of gamma spectrometers. These studies are of great significance because they make it possible to determine the average composition of lunar rocks over great areas.

Phototelevision and photographic images of the surface, obtained by artificial lunar satellites, will make it possible to determine the characteristics of the lunar relief and the geological deciphering of the pictures that are obtained will make it possible to determine the nature of the lunar structures in the processes of their formation. Thus, for example, it has been found that the process of formation of craters with diameters less than 1 kilometer is basically of a shock-explosive nature, which was supported by the research carried out by means of the "Lunokhod-1."

The large scale photographs and charts of the lunar surface are necessary for selecting points at which to carry out further studies of the Moon.

By carrying out studies of the micrometeoritic fluxes in space around the Moon, one can establish the nature of the processes of the formation of the lunar surface under the influence of micrometeoritic bombardment. In addition, these studies are necessary for an understanding of the problem of the safety of spaceflights.

Studies of the magnetic field in space near the Moon will make it possible to obtain information about the intrinsic field of the Moon, the magnetosphere of the Earth, the interplanetary magnetic field and the interaction between them. The results of these studies will make it possible to determine the deep structure of the lunar core, the nature of the distribution of various rock over the surface of the Moon, etc. Combining these studies with research on the magnetic properties of samples brought back to Earth, we can study their nature of the changes in the magnetic field of the Moon and space around the Moon in the course of geological development.

Studies of cosmic radiation in space near the Moon are of great interest to understanding the processes taking place in the solar system and beyond it. On the basis of the products of the reactions that occur as a result of this interaction, we can determine how long a given fragment has been lying on the surface and has been subjected to the action of cosmic rays. And this makes /117
it possible to determine the age of the lunar craters and the processes of their formation. It has already been established that the transformation of the lunar surface is proceeding with unusual slowness, at a rate thousands of times slower than that on Earth.

As we can see from the above, the work of lunar satellites is virgin territory.

We can assume that the research carried out in space near the Moon by the "Luna-19" automatic station will provide new information which will enable scientists to move forward in understanding the secrets of the Moon.

What Are You Like, Lunar Mountains?

The Soviet automatic stations in the "Luna" series, the "Lunokhod-1", the American spacecraft in the "Surveyor" series and the "Apollo" manned spacecraft have made it possible to obtain considerable detailed information on the surface layer of the lunar Maria. But of what rocks are the lunar continents composed, whose area makes up four-fifths of the lunar surface? This problem is enormously intersting to scientists, since, if we know the composition of the rocks that make up the lunar continents we can answer one of the most important questions that science has regarding the Moon — does it have a solid basalt crust like the Earth, or has it undergone partial melting, so that the lava has emerged on the surface only in the areas of the lunar Maria? If the second assumption is true, we can expect that most of the surface of the Moon was formed by primary, undifferentiated material similar in composition to a stony meteorite.

Apparently, during the initial period of its existence, the Moon like the Earth was heated by the heat liberated in the course of decay of radioactive elements. As a result, the fraction with the lowest melting point melted and flowed out on the surface. Hardening rapidly, it formed the lunar crust. Differentiation of the material then took place vertically: the heaviest fractions, iron, titanium oxides, formed on the bottom of the lava lakes, and above them were layers of different minerals of lesser density, many kilometers thick.

This can be used to explain the secret of the "mascons" and the unusual seismic characteristics of the Moon. It is obvious that these processes were largely influenced by the small dimensions of the Moon and the lack of an atmosphere there.

The lack of air on the Moon is due to the fact that its surface remained practically unchanged following tectonic processes that occurred hundreds of millions and possibly billions of years ago. This will make it possible to /118 estimate the geological history of the Earth, since traces of similar processes have practically disappeared completely on our planet — they have been hidden beneath the thickness of sedimentary rocks. This is why the area where the second lunar geologist, the "Luna-20" automatic station landed was selected to be a continental mountainous area located between Mare Imbrium and Mare Crisium. The "Luna-20" automatic station was launched toward the Moon on the 14th of February 1972. After traveling 105 hours along the familiar route through space, the station approached the Moon and entered selenocentric orbit during the braking sequence. Making a soft landing in a mountainous area of the Moon was a very difficult problem. However, the "Luna-20" automatic device solved it successfully. The radio altimeters (high and low altitude) worked accurately and reliably, as did the Doppler velocity meters, control systems, orientation and stabilization systems, motor assembly, radio systems and other systems of the station. On the 21st of February, obeying commands from Earth, the "Luna-20" descended from orbit and at 2219 Moscow time made a soft landing in the area designated. Onboard telephotometers transmitted a panorama of the landing site to Earth and enabled the operators to select an area for collecting soil.

On command from Earth, the soil collecting apparatus went into action. The rock at the place where the samples were collected turned out to be rigid; 3 times during the operation the drill was shut off by the overload protector. Finally all of the problems associated with collecting and packing the soil into the capsule of the return section had been solved.

The pyrotechnic fittings were triggered. The lid of the hatch slammed shut and sealed the capsule. The drill was dropped off. The program for taking off from the Moon was transmitted along the command radio channel to the memory block of the system. Preparation for launching was complete. It remained only to ensure that the Earth and Moon were in the appropriate positions in space. In accordance with the calculations of the ballisticians, on the 23rd of February at 0158 the "Luna-20" lifted off from the landing platform and headed back to Earth. The hermetically sealed compartment contained "pieces" of the lunar continent. The telemetric information indicated that the vertical takeoff had gone smoothly. The engine assembly operated for the required period of time and gave the rocket a velocity that was necessary for overcoming lunar gravitation, 2.7 kilometers a second.

The rocket left the zone where the Moon's gravity predominated and entered the zone of attraction of the Earth; its flight speeded up. On the 25th of February, as it approached our planet, the returning apparatus separated from the rocket. Like a meteorite, it entered the atmosphere at the second cosmic velocity, was braked in its dense layers and landed softly at the designated area by parachute at 2219 Moscow time.

The space marathon had been completed successfully. The search party had a difficult problem to solve. In the middle of the night, in snow and ice, /119 with heavy cloud cover, they had to find the returned stage of the "Luna-20" station. However, even as it was entering the atmosphere of the Earth the ground stations were tracking the apparatus, aircraft radio devices were following its descent, and the exact landing site was spotted from a helicopter.

One more trip through the air and the capsule with the lunar soil was brought to the receiving laboratory of one of the institutes of the Academy of Sciences of the USSR.

So here was the material from the lunar continent. How different it was in external appearance from the regolith of the lunar Maria. The operators extracted it from the drill with difficulty because the forces of internal adhesion were so great. it was silvery grey in color, with a few individual large particles of the same color measuring 4 to 5 mm. Could this be why the lunar continents seem brighter from Earth than the lunar Maria?

The lunar soil, brought back by the "Luna-20" station, was at the disposal of the scientists. It seemed that it would be possible to answer the question of how the lunar mountains were formed which are made of this substance.

Probably new secrets of our nearest neighbor in space, the Moon, will be discovered!

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